GIIGNL

LNG CUSTODY TRANSFER HANDBOOK

FOURTH EDITION version 4.00

DOCUMENT STATUS AND PURPOSE

This fourth (2015) edition of the GIIGNL LNG Custody Transfer Handbook reflects GIIGNL's understanding of best current practice at the time of publication.

The purpose of this handbook is to serve as a reference manual to assist readers to understand the procedures and equipment available to and used by the members of GIIGNL[*] to determine the energy quantity of LNG transferred between LNG ships and LNG terminals. It is neither a standard nor a specification.

This handbook is not intended to provide the reader with a detailed LNG ship-shore custody transfer procedure as such, but sets out the practical issues and requirements to guide and facilitate a skilled operator team to work out a suitable procedure for a specific LNG ship-shore custody transfer application.

Due to the rapidly changing market conditions, new (commercial) opportunities arise leading to new technical solutions and different operations (such as partial unloading, reloading at an LNG import terminal, ship-to-ship LNG transfer operations, development of the small scale LNG market not only with much smaller LNG ships and in much smaller quantities, but also with a different ship design and other cargo containment systems), the GIIGNL General Assembly requested the GIIGNL Technical Study Group to review and update the third edition (version 3.01 – March 2011) of the GIIGNL LNG Custody Transfer Handbook. Therefore, this fourth edition must be seen as an extensive revision of the previous version including not only custody transfer from a large scale LNG ship to an onshore terminal (or vice versa), but also containing a lot more useful information with regard to ship-to-ship LNG transfer and custody transfer from an onshore terminal to small LNG carriers. However it is not specifically intended to work out procedures for overland LNG custody transfer operations involving LNG trucks, containers or trains, or for small scale LNG transfer such as bunkering or refuelling of ships and trucks. For these, kind reference is made to the GIIGNL Retail LNG / LNG as a fuel handbook.

No proprietary procedure, nor particular manufacture of equipment, is recommended or implied suitable for any specific purpose in this handbook. Readers should ensure that they are in possession of the latest information, standards and specifications for any procedures and equipment they intend to employ.

GIIGNL, and any of its members, disclaims any direct or indirect liability as to information contained in this document for any industrial, commercial or other use whatsoever.

This latest version replaces all previous editions of the custody transfer handbook. Please always consult the GIIGNL website www.giignl.org to check for the latest version of this handbook, esp. when referring to a pdf download or a printout of this handbook.

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[*] GIIGNL Groupe International des Importateurs de Gaz Naturel Liquéfié – Paris
(International Group of Liquefied Natural Gas Importers – Paris, France)

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1. INTRODUCTION

Following the publication in 1985 by the N.B.S. of its study "LNG Measurement - A User's Manual for Custody Transfer" [8], the Executive Committee of the GIIGNL (Groupe International des Importateurs de Gaz Naturel Liquéfié) considered it would be useful to write a handbook, as simple and as practical as possible, aimed at organizations involved in the measurement of the energy transferred in the form of LNG in the context of a LNG purchase and sales agreement, whether this sale be F.O.B. [Port of loading], D.E.S. or C.I.F. [Port of unloading].

During its session of October 1987, the General Assembly of GIIGNL decided that this practical handbook should be drawn up by a Study Group comprising companies of the GIIGNL and coordinated by Distrigas S.A (B).

The methods described in this handbook could serve to improve existing procedures. They could also be used in purchase and sales agreements for the GIIGNL members and serve as a reference in new import agreements.

This handbook is based on the measurement methods most used by GIIGNL members.

Detailed tests of the apparatus used can be found in "LNG Measurement Study" of N.B.S. [8].

We wish to thank the companies – BG (UK) - Distrigas Boston (USA) - Enagas (E) - Kansai Electric Power Co (JP) - Snam (I) - Tokyo Electric Power Co (JP) - Tokyo Gas Co Ltd (JP) - Ruhrgas (D) – CMS Energy Trunkline LNG (USA) for their co-operation in producing this handbook, and more particularly Gaz de France for drawing up Sections 6 and 7 of this handbook and Osaka Gas Co Ltd for co-coordinating the studies of the Japanese companies.

SECOND EDITION, OCTOBER 2001

Following the publication of the ISO 13398:1997 standard "LNG - Procedure for custody transfer on board ship", the GIIGNL General Assembly requested the GIIGNL Study Group to revise the original edition (March 1991) of this GIIGNL LNG Custody Transfer Handbook, particularly taking into account this new ISO standard.

All 13 sections of the original edition have been reviewed and updated where appropriate. The following sections have been thoroughly revised:

2. General description of the measurement
3. Volume measurement
6. Sampling of LNG
7. Gas analysis

Moreover, a new section was added:
14. LNG Sales contract custody transfer checklist.
Worked out examples for LNG density and GCV have been rearranged in Appendices 1 and 2.

We wish to thank all companies and organizations and their delegates who together contributed to this second edition, viz. (in alphabetical order):

Advantica Technologies Ltd. (UK)
BG International (UK)
CMS Energy Trunkline LNG Company (USA)
Distrigas (B)
Enagas (E)
Gaz de France (F)
Nigeria LNG (NI)
NKKK (JP)
Osaka Gas (JP)
Rete Gas Italia (I)
SIGTTO (UK)
Tokyo Gas (JP)
Tractebel LNG North America (USA)

THIRD EDITION, MARCH 2010

Since the second edition, several new international standards and revisions of existing international standards related to the subject of this handbook, have been published or are forthcoming. Also, technologies and best current practices evolved in this past period. Therefore, the GIIGNL General Assembly requested the GIIGNL Technical Study Group to revise the second edition (October 2001) of the GIIGNL LNG Custody Transfer Handbook, with the upcoming new ISO standard ISO 10976 “Measurement of cargoes on board LNG carriers”, which will replace and supersede the current ISO 13397 (1997) standard upon its publication.

Moreover this third edition of the handbook has been updated and revised as appropriate to streamline it with new or revised international standards such as ISO, EN and other standards. These include:

- EN 437: Test Gases – test Pressures – Appliance Categories - Edition 2003
- ISO 8943 Refrigerated light hydrocarbon fluids — Sampling of liquefied natural gas — Continuous and intermittent methods - Edition 2007
- ISO 6974-6 Natural gas - Determination of composition with defined uncertainty by gas chromatography - Part 6: Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons using three capillary columns - Edition 2002
- ISO 16664: Gas analysis - Handling of calibration gases and gas mixtures – Guidelines - Edition 2004
- ISO 4259: Petroleum products - Determination and application of precision data in relation to methods of test - Edition 2006
- ISO/TR 24094: Analysis of natural gas - Validation methods for gaseous reference materials – Edition 2006
- ISO 10723: Natural gas – Performance evaluation for on-line analytical systems – Edition 2002
- ISO 6326-1: Natural gas – Determination of Sulphur compounds – Part 1: General introduction – Edition 2007
- ISO 6327: Gas analysis – Determination of the water dew point of natural gas – Cooled surface condensation hygrometers - Edition 2007
- ISO 19739: Natural gas - Determination of sulphur compounds using gas chromatography - Edition 2004

- ISO 12213-1 -2 -3: Natural gas – Calculation of compression factor - Edition 2006
- ISO 15112: Natural gas - energy determination - Edition 2007
- ISO 18132-1: Refrigerated light hydrocarbon fluids – General requirements for automatic level gauges – Part 1: Gauges onboard ships carrying liquefied gases – Edition 2006
- ISO 18132-2: Refrigerated light hydrocarbon fluids – General requirements for automatic level gauges – Part 2: Gauges in refrigerated-type shore tanks – Edition 2008
- ISO/DIS 28460: Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship to shore interface and port operations – Edition 2009

All 14 sections, enclosures and appendices of the second edition have been exhaustively reviewed and updated where appropriate.

We wish to thank all 20 companies and organizations and their delegates who together contributed to this third edition, in alphabetical order:

ActOn LNG Consulting - UK
Botas - Marmara Ereglisi – Turkey
BP – Sunbury-on-Thames - UK
Distrigas of Mass.- GDF Suez- Everett (Boston) USA
Dragon LNG - Milford Haven – UK
Elengy - GDF Suez - Paris - France
Enagas - Spain
Exxon Mobil - Houston - TX – USA
Fluxys LNG - Zeebrugge – Belgium
Gas Natural - Madrid – Spain
GL- Noble Denton - Loughborough – UK
Kogas – Seoul – South Korea
National Grid – Grain LNG - UK
Osaka Gas – Osaka - Japan
Shell Global Solutions- The Hague– The Netherlands
RasGas - Ras Laffan – Qatar
REN Atlantico - Sines – Portugal
Sempra LNG - San Diego - CA – USA
SGS - Belgium
SIGTTO - London – UK
Tokyo Gas - Tokyo – Japan
Total – Paris - France

FOURTH EDITION, FEBRUARY 2015

Due to the rapidly changing market conditions, new (commercial) opportunities arise leading to new technical solutions and different operations (such as partial unloading, reloading at an LNG import terminal, ship-to-ship LNG transfer operations, development of the small scale LNG market not only with much smaller LNG ships and in much smaller quantities, but also with a different ship design and other cargo containment systems), the GIIGNL General Assembly requested the GIIGNL Technical Study Group to review and update the third edition (version 3.01 – March 2011) of the GIIGNL LNG Custody Transfer Handbook.

Furthermore there is a continuous evolution in the LNG (sampling) technology and this fourth edition tries to incorporate and be in line with new or revised international standards.

All sections, enclosures and appendices have been thoroughly reviewed, amended and updated where appropriate. Especially Sections 6 and 7 have been adapted to streamline it with the current best practices. To make this handbook more readable, most of the examples have been replaced to the appendices. Moreover, all sections with regard to the uncertainty of the energy determination have been moved to Section 15 and the following sections have been added:

- 2.6 Gassing-up and cooling down operations
- 15.8 Rounding of numbers
- 16. Ship-to-ship LNG transfer operations
- 17. Small LNG ship to shore transfer operations
- 18. Reloading operations in regasification terminals

With regard to these new Sections 2.6, 16, 17 and 18, the aim of this GIIGNL LNG Custody Transfer Handbook is to integrate the specific conditions for this special operations of gassing-up and cooling down, for ship-to-ship LNG transfer, for small LNG ship-to-shore transfer (or vice versa) and for reloading operations at regasification terminals, but not to integrate the small scale LNG transfer operations (such as bunkering or fuelling of ships and trucks, and filling of LNG trucks or containers).

We wish to thank all companies and organisations and their delegates who together contributed to this fourth edition, in alphabetical order:

Botas – Marmara Ereglisi – Turkey
BG Group – Houston – Texas
Enagas - Spain
Fluxys LNG – Zeebrugge – Belgium
Gas Natural Fenosa – Spain
Gate Terminal – Rotterdam – The Netherlands
GDF Suez – Paris – France
National Grid – Grain LNG – UK
RasGas – Ras Laffan – Qatar
Shell Global Solutions – The Hague – The Netherlands
Tokyo Gas – Paris – France
Total – Paris - France

2. GENERAL DESCRIPTION OF THE MEASUREMENT

Accuracy

The term “measurement accuracy” is defined in the most recent version of the International Vocabulary of Metrology (JCGM_200:2012) as “closeness of agreement between a **measured quantity value** and a **true quantity value** of a **measurand**”. Measurement error is defined as **measured quantity value** minus a **reference quantity value.**

Uncertainty, combined standard uncertainty and expanded uncertainty

The terms “measurement uncertainty”, “combined standard uncertainty” and “expanded uncertainty” (see Section 15) are used as defined in the JCGM 100:2008 document: “Evaluation of measurement data – Guide to the expression of uncertainty in measurement”.

2.1. GENERAL FORMULA FOR CALCULATING THE LNG ENERGY TRANSFERRED

The formula for calculating the LNG transferred depends on the contractual sales conditions. These can relate to several types of sale contract as defined by Incoterms 2010. In case of rules for sea and inland waterway transport, the most commonly used are a FOB sale, a CFR sale or a CIF sale.

In the case of a FOB (Free On Board) sale, the determination of the energy transferred and invoiced for will be made in the loading port. There is another sale contract similar to FOB, named FAS (Free Alongside Ship).

In the case of a CIF (Cost Insurance & Freight) or a CFR (Cost and Freight) sale, the energy transferred and invoiced for will be determined in the unloading port.

Other rules exist for any mode of transport which can hence also apply for maritime transport such as DAT (Delivered At Terminal) and DAP (Delivered At Place).

In FOB contracts, the buyer is responsible to provide and maintain the custody transfer measurement systems on board the vessel for volume, temperature and pressure determination and the seller is responsible to provide and maintain the custody transfer measurement systems at the loading terminal such as the sampling and gas analysis. For CIF and CFR (and DES according to Incoterms 2000) contracts the responsibility is reversed.

Both buyer and seller have the right to verify the accuracy of each system that is provided, maintained and operated by the other party.

The determination of the transferred energy usually happens in the presence of one or more surveyors, the ship's cargo officer and a representative of the LNG terminal operator. A representative of the buyer can also be present.

In all cases, the transferred energy can be calculated with the following formula:

$$E = (V_{LNG} * D_{LNG} * GCV_{LNG}) - E_{gas\ displaced}$$
$$\pm E_{gas\ to\ ER}\text{, if applicable}$$

where:

E = the total net energy transferred from the loading facilities to the LNG carrier, from the LNG carrier to the unloading facilities or from one LNG carrier to another LNG carrier (ship-to-ship LNG transfer). In international LNG trading, the energy transferred is most frequently expressed in millions of British Thermal Units (10^6 BTU or MMBTU) although this is not a SI energy unit. Therefore, MMBTU is the preferred unit in this handbook. A conversion factor table for other commonly used energy units (such as MWh) can be found in Enclosure 1.

V_{LNG} = the volume of LNG loaded or unloaded in m^3.

D_{LNG} = the density of LNG loaded or unloaded in kg/m^3.

GCV_{LNG} = the gross calorific value of the LNG loaded or unloaded in MMBTU/kg. The gross calorific value is generally used in international LNG trading rather than the net calorific value, see Enclosure 4.

$E_{gas\ displaced}$ = the net energy of the displaced gas, also in MMBTU, which is either:
- sent back by the LNG carrier to shore or to another LNG carrier when loading (volume of gas in cargo tanks displaced by same volume of loaded LNG),
- or, gas received by the LNG carrier in its cargo tanks when unloading in replacement of the volume of discharged LNG.

$E_{gas\ to\ ER}$ = if applicable, the energy of the gas consumed in the LNG carrier's engine room (also including all gas burnt by the ship's GCU (Gas Combustion Unit)) during the time between opening and closing custody transfer surveys, i.e. used by the vessel during the LNG transfer operation, which is:
+ for an LNG loading transfer or
- for an LNG unloading transfer

For simplicity, the parties may also make a commercial decision to mutually agree a fixed gas quantity/volume to estimate $E_{gas\ displaced}$ and/or $E_{gas\ to\ ER}$.

2.2. GENERAL SCHEME OF THE MEASUREMENT OPERATIONS

The objective is to measure the quantity of energy loaded from production facilities into an LNG carrier, or unloaded from an LNG carrier to a receiving terminal. For ship-to-ship operations, the objective is to measure the quantity of energy transferred from one LNG carrier to another LNG carrier.

From the above formula, it can be inferred that five elements must be measured and/or calculated:

- LNG volume,
- LNG density,
- LNG gross calorific value,
- energy of the gas displaced during the transfer of LNG,
- energy of any gas consumed in the LNG carrier's engine room during (un)loading operations.

A graphic overview of the measurement scheme is shown in the figure "Flowchart for determining the energy transferred" (see the flowchart in Section 2.2.5)

2.2.1. LNG Volume

The standard method chosen for measuring the volume of LNG transferred is based on the LNG carrier's instruments, mainly the use of level gauges and calibration tables.

For most of the vessels, gauging has become automated via the LNG carrier's custody transfer measurement system. These systems are capable of drawing up reports of the volume of LNG on board at any time during (un)loading. This is achieved by converting the measured LNG levels in each cargo tank into the corresponding LNG volume in the cargo tank via the level-to-volume conversion tables and by applying correction factors for trim, list and temperature and then by totalling the volumes in all the individual cargo tanks. Further details are given in Section 3.2.7.

Usually a quantity of LNG, called a 'heel', remains on board after unloading so as to keep the tanks cold. However, operators may sometimes prefer to strip out the cargo tanks partially in order to maximize the LNG delivery or totally before the LNG vessel is scheduled for dry-docking.

Determination of the volume transferred requires two sets of measurements, an initial one before starting loading or unloading and a final one at the end of the procedure. These are called the opening and closing custody transfer surveys (CTS) respectively. Two LNG volumes result and the difference between the larger volume and the smaller volume represents the volume of liquid transferred.

For an accurate volume measurement it is recommended that LNG piping on the LNG carrier's deck including manifolds be in an identical inventory condition during both custody transfer surveys (CTS). The piping should either be completely filled with LNG both during the opening custody transfer (i.e. before (un)loading) and the closing custody transfer (i.e. after (un)loading) or, provided that draining is possible before the closing CTS, alternatively be drained during both the opening and closing CTS. Where the piping is drained before or after the CTS measurement, it should be done for sufficient time to fully empty the piping.

As good practice it is recommended that the initial level gauging should be made prior to any cooling down operation, i.e. after the (un)loading arms have been connected but before any ship's liquid and vapour manifold valves have been opened. Where the opening CTS is conducted prior to commencement of tank cool down, the CTS reading, where automated, may show some liquid in the tank(s). The system should have the capability of 'zeroing' such readings for level and volume, since otherwise any liquid recorded at commencement will be deducted from the final CTS volume.

The final level gauging reading shall be made as soon as possible after completion of (un)loading with liquid and vapour arms (or flexible hoses) drained and inerted, and with liquid and vapour manifold valves closed.

The level gauge readings shall be determined by the arithmetic average of several successive readings at regular intervals. Further details are provided in Sections 3.2.1, 3.2.2 and 3.2.3.

In the event of failure of the primary level gauging device, an auxiliary device should be used.

Level corrections are to be made using correction tables provided for the LNG carrier as tank gauge tables for trim, list and also for temperature. Most LNG carriers are equipped with process control systems or stand-alone systems able to perform these corrections automatically. It is recommended to use the millimetre as the smallest unit of dimension, when applying a tank gauging table.

In some cases the LNG carrier must be completely emptied after the unloading operation, e.g. before a long period of inactivity. In this case a special procedure explained in Section 3.2.6 is followed for determination of the volume transferred.

Before loading operations, the LNG carrier may be in "ready-to-load" condition or otherwise, may require gassing-up and/or cooling down operations. In this case a special procedure explained in Section 2.6 is followed for determination of the energy and volume transferred.

Unless parties explicitly agree otherwise (see below), gas flow is stopped and appropriate gas valve(s) to engine room shut and sealed during and between the opening and closing custody transfer surveys.

The possibility of using LNG and/or boil-off gas as fuel for the ship during transfer is considered in Sections 2.1, 2.3.4 and 12.2.

Since the calculation methods described in this handbook are based on volumes of LNG and LNG vapour before and after transfer, any use of LNG, regasified LNG and/or LNG vapour during the transfer should be fully accounted for by correction of V_{LNG}, according to the terms of the LNG purchase and sales agreement.

Note: In-line measurement of LNG quantity

Coriolis mass flow meters and ultrasonic flow meters are in use at some (un)loading terminals. However, at the time of writing, their use as part of a ship-shore custody transfer measurement system is not yet conventional. This is mainly due to their high cost, the inability of these flow meters to handle high flow rates and "proving" issues. For small scale LNG transfer operations these meters can be used as secondary (or even as primary system), if agreed upon by the parties in their commercial sales conditions, or just as (operational) verification for the parties involved. A further informative discussion can be found in Appendix 1.

2.2.2. LNG Density

The density of LNG is determined by calculation from the measured composition of the LNG transferred and the temperature of the LNG measured in the LNG carrier's tanks.

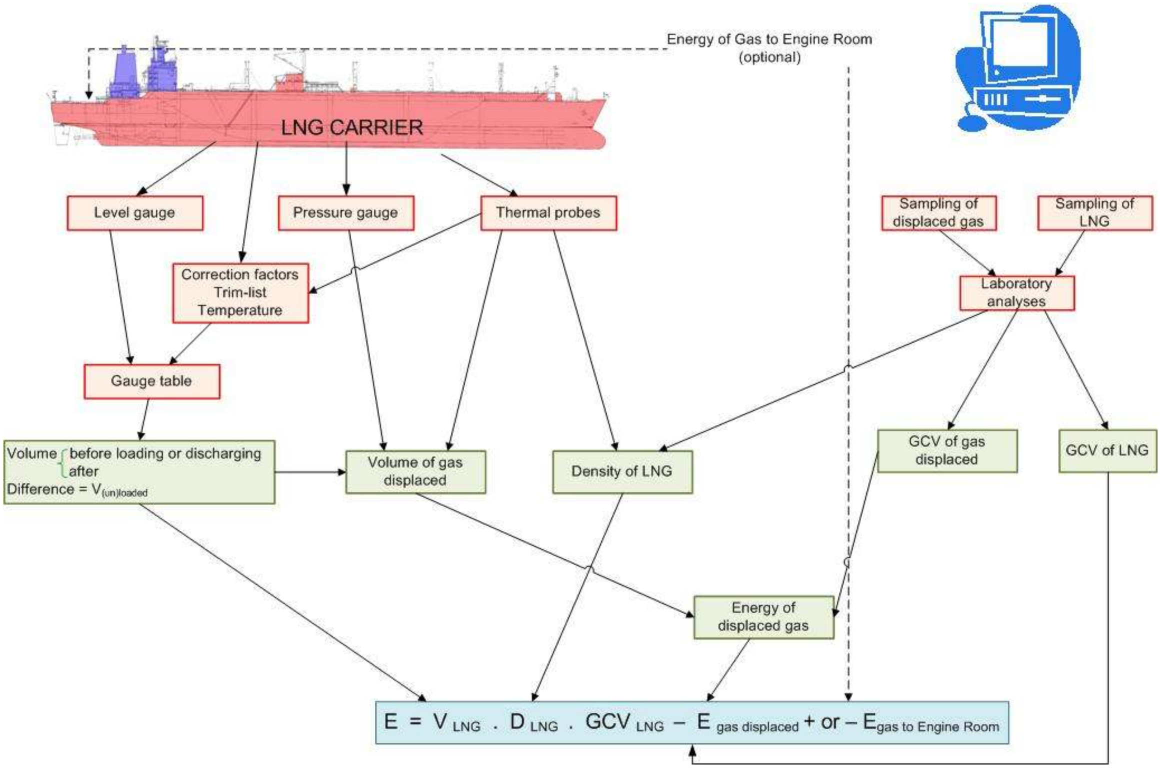
2.2.3. LNG Gross calorific value

The composition of the LNG is used to calculate the gross calorific value.

2.2.4. Energy of the gas displaced by the transfer of LNG

This energy is calculated according to the composition and volume of the gas displaced, and the pressure and temperature of the gas inside the tanks of the LNG carrier before loading or after unloading. The calculation procedure is explained in Section 12.1.

2.2.5. Flowchart for determining the energy transferred



2.3. INSTRUMENTS USED

2.3.1. For the determination of the LNG volume

For the determination of the LNG volume the following are required:

- the LNG carrier’s calibration tables, including the main gauge tables for each tank and different correction tables accounting for list and trim variances (if any) for the main and secondary gauging systems, tank contraction tables for Moss-type and SPB-type cargo containment systems, and possibly, other correction tables according to the type of level measuring devices,
- the equipment for measuring the level of LNG in the LNG carrier's tanks. Each cargo tank usually has two level gauge systems installed, one designated as 'main' or 'primary' and the other as 'secondary'. Capacitance and microwave (radar) level gauging systems are widely used as primary CTS systems onboard LNG tankers, backed up by a secondary CTS system generally consisting of a float gauging system,
- recently a laser system (called LIDAR) was introduced in the industry but at the time of writing its use is restricted to very few LNG carriers. A further informative discussion can be found in Appendix 2. Some very old LNG carriers still in operation are fitted with nitrogen bubbler systems, which rely on good knowledge of the LNG density to give accurate readings,
- temperature probes distributed over the height of the LNG carrier's tanks,
- other measuring devices required for applying the correction factors.

Note: Automated systems

The calculation to determine LNG volume may be automated by processing the level, temperature and pressure measurements, taking into account the above mentioned calibration and correction tables to produce a report meeting CTS requirements. LNG carriers may be fitted with certified custody transfer measurement systems for this purpose. See Section 3.2.7.

2.3.2. For the determination of LNG density and gross calorific value

The determination of the density and the gross calorific value of the LNG transferred is made on the basis of the average composition of the LNG obtained by:

- continuous or discontinuous sampling of LNG in the LNG transfer line(s) between the ship and the terminal,
- gas chromatographic analysis,

followed by:

- a calculation based on the average composition of the LNG, its average temperature and the coefficients given by the National Bureau of Standards for the density [9],
- a calculation based on the average composition of LNG and characteristics of elementary components (GCV, molar volume, molar weight) given by reference tables or standards for the gross calorific value.

At a loading terminal LNG sampling and analysis are made in the LNG transfer line(s) prior to possible flashing (vaporization) in the ship's cargo tanks. If flashing occurs in the ship's cargo tanks, then this causes a minor change in LNG composition since the most volatile components (typically nitrogen and methane) are preferentially vaporized and returned to shore via the vapour return line. Therefore, this effect should be avoided if possible, or otherwise minimized, e.g. by ensuring that the tank pressure in the ship's cargo tanks is sufficiently higher than the saturated vapour pressure of the LNG being loaded.

Notes for information only:

A novel LNG analysis method

At the time of publication of this fourth edition, a different measurement device for analysing LNG composition based on direct analysis in the LNG transfer line(s) hence eliminating the need of an LNG sampling device, vaporizer and gas analyzer, is being tested in a few pilot applications (see Section 7.6 Raman spectroscopy).

2.3.3. For the determination of the energy of displaced gas

The energy of the displaced gas can be determined from:

- sampling of the gas displaced,
- a gas chromatographic analysis of this sample gas, enabling the GCV to be calculated,
- pressure and temperature measurements within the LNG carrier's tanks.

However, for the determination of the energy displaced, some parameters such as pressure, gas composition and temperature can be estimated from experience and taken as constant for both custody transfer surveys before and after (un)loading.

For instance, the displaced gas may be assumed to be a fixed mixture of nitrogen and methane, or pure methane. This assumption will hardly increase the overall uncertainty.

2.3.4. For the determination of the energy of "Gas to engine room"

Parties may explicitly agree to allow gas consumption in the LNG carrier's engine room (also including the gas burnt by the ship's GCU) during the time between the opening and closing custody transfer surveys (CTS's). This could be to ensure low air-emission operation in the engine room whilst at berth and so may favour the use of boil-off gas perhaps complemented by regasified LNG rather than fuel oil in the engine room. This practice may enable the LNG carrier operator to comply with MARPOL Annex VI (revision October 2008).
For (re)loading operations or ship-to-ship LNG transfer operations, this could also be done on the LNG carrier(s) in order to handle the boil-off gas (flash gas) produced during such operations, hence reducing the vapour returned to shore or to the vessel being unloaded.

It is recommended in this case that the LNG carrier has proper measuring equipment on board and procedures accepted by both parties to accurately measure the gas energy consumption in the engine room between the opening and closing custody transfer surveys (CTS's), and that this on-board gas energy consumption is taken into account as "Gas to Engine Room" as per the general formula in Section 2.1. However, for simplicity the parties may make a commercial decision to mutually agree to a fixed gas quantity/volume.

2.3.5. Periodic instruments recalibration

It is recommended that, unless it is specified by the fiscal authorities or by the Classification Society, Buyer and Seller agree on the periodicity of recalibration intervals, e.g. at each dry-docking.

2.4. STANDARDIZATION

International standards exist for the classical methods and techniques used for LNG Custody Transfer such as ISO 6976 for calculation of the GCV of gas.

On the other hand, a number of existing LNG supply, shipping and purchase agreements specify GPA 2261-2000 for gas chromatography and HM 21 or GPA 2145-2009 and GPA 2172-2009 for the calculation of the GCV of the gas. Buyer and Seller may approve one of these editions, usually the most recent edition.

As far as methods and techniques dealing with static measurement procedures for LNG are concerned, it should be noted that ISO has issued numerous international standards, (see Enclosure 2). The recommendations included in these documents and future international standards are appropriate to be considered for new agreements.

2.5. PARTIAL LOADING OR UNLOADING OF LNG CARRIERS

In recent years there has been a worldwide increase in short term and spot cargo LNG trading, involving two new operating trends in LNG shipping:

- more and more LNG shippers are using LNG carriers as floating LNG storage,
- several LNG shippers have considered and some have carried out partial unloading and/or partial loading of one or several cargo tanks of LNG carriers.

When performing such operations, due attention should be given to:

- safe ship/shore operating practices and procedures,
- proper LNG ship/shore custody transfer procedures.

Please refer to Appendix 3 for recommended safe practices for partial (un)loading.

2.6. Gassing-up and cooling down operations

2.6.1. Gassing-up operations

When an LNG vessel is delivered or after dry dock, the cargo tanks are often filled with inert (exhaust) gas. As inert exhaust gas contains carbon dioxide which will freeze during loading, it must be replaced with warm LNG vapor prior to cooling down the tanks in preparation of loading. This process is called gassing-up and is normally preceded by a process of drying and inerting.

Drying can be done with hot air (or nitrogen) and inerting is performed to remove the oxygen out of the cargo tanks and replace the air/oxygen by inert gases (exhaust gases of the ship or nitrogen). In case drying and inerting are performed with nitrogen, both steps can be combined in one operation. The reason behind the preliminary operations of drying and inerting is not to directly replace air by natural gas due to safety reasons (hence avoiding an explosive atmosphere during the operation).

Once inerted, the shore will supply LNG which is sent to the main vaporizer of the ship to produce vapor warmer than the dew point temperature in the cargo tank. This vapor is then injected at the top of the cargo tank to displace the inert gas. The increase of pressure and the difference in density forces the inert gases out of the cargo tanks. The exhaust gas is generally directed to the ship's (forward) vent mast, to a vent on shore or burnt in the terminal's flare (at the beginning it is fully inert and gradually becomes a mixture of nitrogen and inert gases (which percentage is decreasing) and natural gas (which percentage is increasing). This process continues until the exhaust gas is measured to have approx. 98-99% of methane and the CO2-content is less than a certain low threshold (e.g. 0.1%). Once this is accomplished, the vessel is ready to receive cold vapor and start the cooling down process.

The quantity of LNG required for this operation depends on the size and construction of the vessel's cargo tanks. The gas quality considered for gassing up is usually the same as the quality for cooling and for loading, but some loading/reloading facilities can use different gas qualities for each operation. The energy required for gassing-up the cargo tanks is stated in the terminal rules or in the contract between the parties, but the most commonly used technique is to use the certified gassing-up tables of the LNG vessel.

The certified gassing-up tables apply a volume of natural gas which is between 1.7 and 2 times (each LNG vessel has a coefficient) the volume of each cargo tank, which is the theoretical volume of gas to be supplied to each cargo tank for the purpose of gassing-up this cargo tank.

Each vessel will have a gassing-up table for each tank on board. These are provided by the tank manufacturer and confirmed by an independent surveyor during construction at the shipyard. Each table is designed specifically for that particular type of containment system. For example, a 145 000 m³ size vessel will require approx. 420 m^3 of LNG and 2 850 MWh for a complete gassing-up operation. This gassing-up operation will take approx. 20 hours to complete depending upon the LNG supply and the vaporization rate on the vessel. The gassing-up tables should be reviewed and agreed upon by all parties at the preliminary meeting prior to commencing any operations.

There are some terminals which correct the theoretical volume taking into account the measurement conditions when these are different than the ones in the certified gassing-up tables.

Other alternatives to measure the energy for gassing-up (especially for old LNG vessels which do not have certified gassing-up tables) are the following ones:

a) the procedure stated in the LNG vessel Operations Manual,

b) to apply twice the theoretical volume of each cargo tank to obtain the theoretical energy for gassing up,

c) to measure the delivered LNG (in cubic meters) during the gassing-up operation by means of an LNG mass or flow meter,

d) to measure the difference in level in the shore LNG tanks. In this case, it is necessary to take into account any other filling (e.g. cold circulation) or emptying (e.g. send out for regasification purposes) operations of the tanks.

2.6.2. Cooling down operations

Cooling down operations are performed to slowly reduce the temperature of the cargo tanks close to that of the LNG to be loaded in order to avoid any structural damages by thermal shock or stress to the tank construction. The target is to reach a certain reference temperature according to the performance criteria stated in the operations manual or cool down tables of the LNG vessel.

Cooling down operations are generally performed on an LNG ship of which the cargo tanks are under (warm) natural gas (e.g. after a long ballast voyage during which the cargo tanks have been warmed up or (immediately) after gassing-up operations). However it is also possible to cool down an LNG ship of which the cargo tanks have been fully dried and inerted with nitrogen, hence avoiding gassing-up operations.

LNG is supplied by the LNG terminal and it is vaporized and injected at a controlled rate into the ship's cargo tanks through spray nozzles at the top of the cargo tanks to avoid thermal shock in the tanks and its devices (such as pumps, pump columns, probes…). Once the LNG is vaporized, there is an increase of pressure in the cargo tanks and the gas return is sent to the terminal's vapour return system or to the terminal's flare to keep the pressure in the cargo tanks under control. The LNG vessel can also help reducing its cargo tank pressure by burning gas as fuel (in the engines or in the gas combustion unit).

The required temperature needed before loading can be started is identified in the Operations Manual or the cool down tables provided by the tank manufacturer. Each cool down table is specific to that tank type, is issued by the manufacturer during construction and is verified by an independent surveyor prior to the vessel being delivered. The cool down tables identify the quantity and length of time required to complete the operation prior to loading. The gas quality considered for cooling down is usually the same than the quality for loading (and gassing-up if there is any), but some loading/reloading facilities can consider different gas qualities for each operation. The energy required for the cooling down operations of the cargo tanks is stated in the terminal rules or in the contract between the parties, but it is usual to apply the use of the cool down tables or one of the following alternatives.

Cooling down tables
The most common method is the use of the cool down tables. Based on the size of the cargo tank, the manufacturer calculates how many cubic meters of LNG or what energy content are required to lower the temperature inside the tank one degree Celsius. Then based on the vapor temperature inside the tank at the beginning of the operation, the quantity is calculated accordingly. The time it takes to complete a cooling down operation depends on the temperature prior to starting the operation. The cooling down tables should be reviewed and agreed upon by all parties at the preliminary meeting prior to commencing any operation.

Cooling down operations are generally faster than gassing-up operations. It takes approx. 10 to 12 hours for a membrane type LNG vessel and approx. 20 hours for a Moss type vessel.

a) Membrane type LNG vessels

In this type of vessel the reference temperature is the average temperature (vapor phase) of the pump tower in each tank excluding the first top or two top sensors (depending on terminal rules/contract between the parties).

The reference temperature for loading a membrane type LNG vessel shall be approx. -130ºC.

It is usual to use the certified cooling down tables. These tables give the energy required to cool down each tank from its arrival temperature to -130ºC.

The certified cooling down tables have been made up supposing a certain gas type in order to obtain the energy. Once cooling down energy has been obtained, it is possible to obtain an LNG cubic meter equivalent for this cooling down operation.

The tables are divided into two sections:

- Warm conditions. These are used in case the average temperature in the cargo tanks is higher than -40ºC. The table normally spans the range between +40ºC and -130ºC. In this case the operation can take about 10 to 12 hours.
- Cold conditions. These are used in case the average temperature in the cargo tanks is equal to or lower than -40ºC. The table normally spans the range between -40ºC and -130ºC. In this case the operation can take about 6 to 8 hours.

b) Moss type LNG vessels

In this type of vessel the temperature reference is the equatorial temperature of the cargo tanks. The reference temperature for loading a Moss type LNG vessel normally spans the range between -110ºC and -130ºC depending on the operations manual of the LNG vessel.

In this case, the certified cooling down tables could give:

- the LNG volume needed to reduce the equator temperature of the tank by one degree Celsius. The total LNG quantity required for cooling down the cargo tanks will be calculated by multiplying the difference between the initial equator temperature and temperature reference by the value of cubic meters that are needed to lower the equator temperature by one degree Celsius.
- the LNG volume and energy needed to reach the reference temperature (as the equatorial temperature).

Nozzle pressure

The cooling down operations are performed by injecting LNG through special spray nozzles into the cargo tanks. The flow is fully dependent on the applied pressure. The number of nozzles, the average pressure and the duration of the spraying for each tank can be used to determine the volume of LNG used for the cooling down operations.

In case the cooling down operations are performed on an LNG ship of which the cargo tanks are under nitrogen, the cool down tables may be used as well, however this should be agreed upon by all parties.

3. VOLUME MEASUREMENT

3.1. GAUGE TABLES

3.1.1. Use of gauge tables

The gauge tables are numerical tables which relate the height of the liquid in an LNG carrier's tank to the volume contained in that tank. The volume may need to be corrected taking into consideration various factors.

An independent surveyor usually produces the gauge tables during the building of the LNG carrier. They take into account the configuration of the tank, its contraction according to the temperature of the liquid and the volumes occupied by various devices, e.g. cargo pumps.

The calibration tables are usually divided into:

- main gauge tables: height/volume correlation in ideal conditions,

- correction tables taking into account actual conditions of the LNG carrier and its measuring instruments.

For each LNG carrier there is one main gauge table per tank. Generally the volumes are given for heights varying cm by cm, the volume for intermediate heights in mm being calculated by interpolation. An example of a gauge table is given in Appendix 4 (table A4-1).

To avoid these interpolations, which can be a source of inaccuracy, the most-used parts of the gauge tables – i.e. heights between 10 and 60 cm and heights corresponding to a volume between 95% and 98% of the total volume of the tank – are sometimes developed in a fine gauge table and the volumes can be calculated mm by mm. This then reduces the determination of the volume to a mere reading in a table (see Appendix 4, tables A4-2 and A4-3).

The examples used in this section are taken from a vessel with prismatic cargo tanks. The same principles generally apply to those vessels with spherical or other shapes of cargo tanks.

Various methods exist for establishing the gauge tables. The main methods are:

- macro metrology with tapes,
- a laser measuring system,
- a photogrammetric measuring system.

For details of calibration procedures for tanks, reference can be made to existing ISO standards (see Enclosure 2).

3.1.2. Correction tables

The gauge tables are completed with correction tables established according to:

- the condition of the LNG carrier (trim/list),
- the average LNG temperature in the tank that influences contraction or expansion of the tank,
- the temperature in the gaseous phase, and/or the density of the LNG influencing the level measuring devices.

Tank gauge tables may also provide an example of how to conduct the volume calculation using the measurements provided.

It should be noted that LNG carriers normally have two level measurement devices in each cargo tank (and often of two different types). Correction tables are specific to a level gauge. Using the correction tables for the wrong gauge can result in significant inaccuracies.

3.1.2.1 Correction according to the condition of the LNG carrier

The gauge tables are established for an LNG carrier with zero list and trim. Therefore, it will be necessary to correct the height reading to take into account a list or a trim which is not zero.

Correction tables are made up according to:

- the position of the gauge in the tanks,
- the list of the LNG carrier (see Figure 1,),
- the trim of the LNG carrier (see Figure 2,),

These corrections can be positive or negative. So the real height will be equal to the algebraic sum of the height reading, the correction for list and the correction for trim. These tables are made up in degrees for the list and in metres for the trim, with fixed steps of variation. For intermediate values, the correction will be calculated by interpolation.

In practice, the LNG carrier's cargo officer will usually manage the vessel's ballast to obtain zero or a limited list and trim.

3.1.2.2 Corrections according to the temperatures in the liquid and gaseous phases

The corrections are related to the volume variations resulting from the contraction of the tanks and their insulation according to the temperature of the liquid and gaseous phases.

This phenomenon is significant for LNG carriers with self-supporting tanks. Appendix 4 gives an example of these tables (see table A4-4).

3.1.3. Approval by authorities

The gauge tables may be approved by either the authorities of the countries concerned with the LNG sale and purchase or by independent sworn measurers. In practice, largely due to the importance for LNG shipping of the Japanese market and its requirement for NKKK certification, the great majority of LNG carriers have such certification.

This approval may be valid for a limited duration, generally 10 to 12 years, or less depending on LNG terminal requirements, provided there are no modifications to the tanks. For the European Union, this approval corresponds to a community directive.

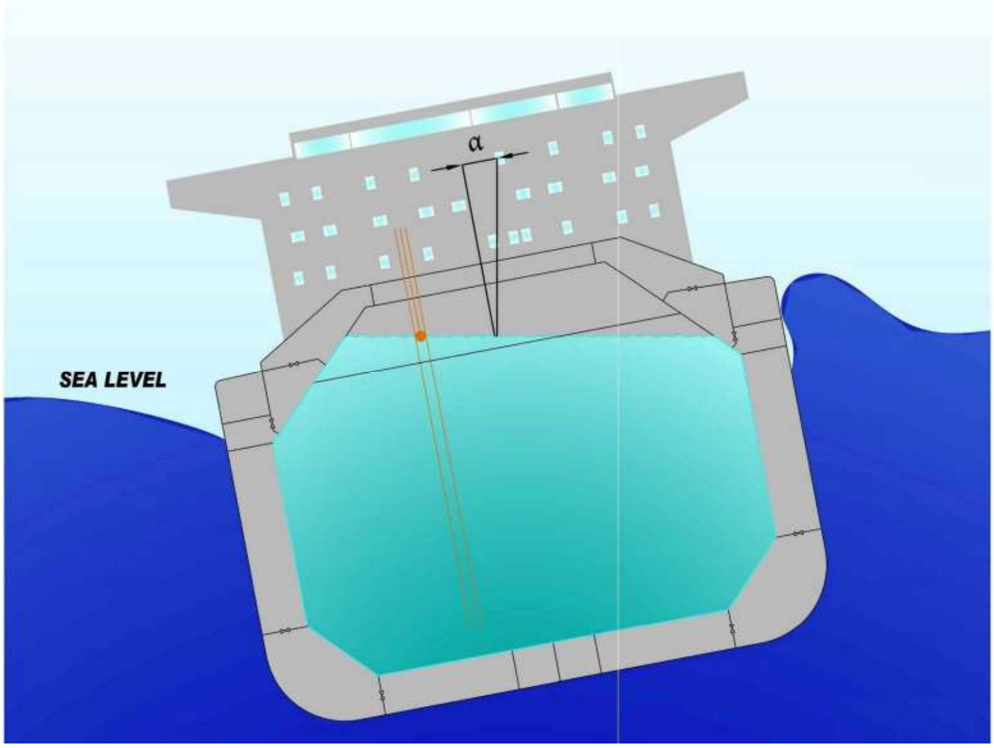
When an LNG carrier is put into operation, a list of all works on the tanks must be supplied, and the tanks must be inspected for any modifications which might affect the volume.

In the case of any distortion or modification to a tank, the gauge table must be adjusted accordingly.

The applicable and confirmed standards correspond to:

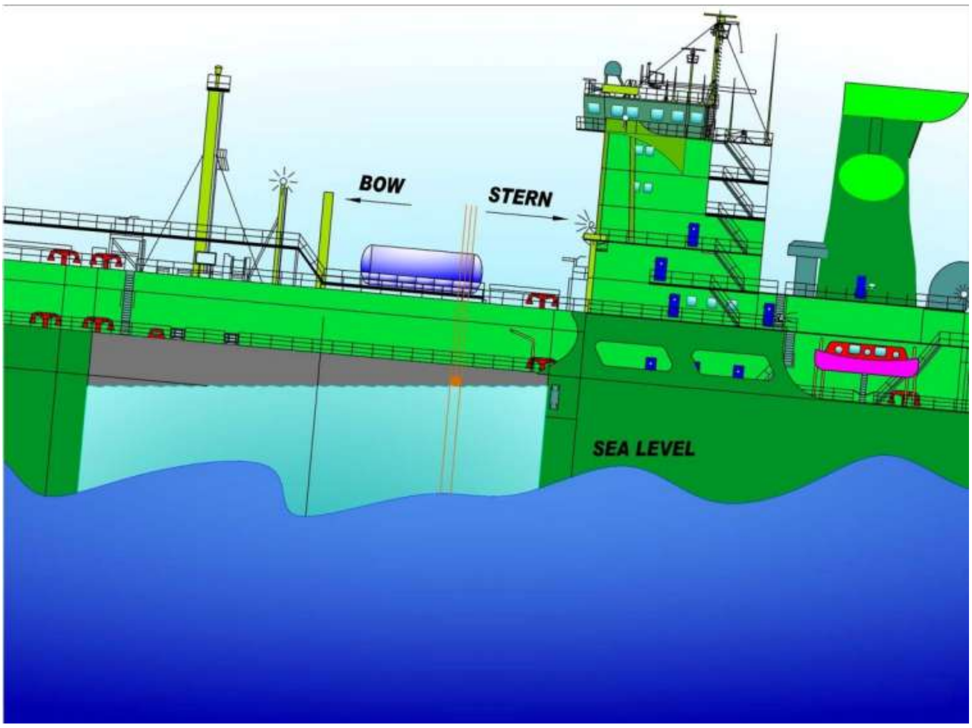
- ISO 8311:2013 Refrigerated light hydrocarbon fluids – Calibration of membrane tanks and independent prismatic tanks in ships – Physical measurement,

FIGURE 1



List represented by the angle α in degrees to port. In this illustrative case, the correction will be negative.

FIGURE 2



Trim expressed in metres or fractions of a metre, according to the difference in bow and stern drafts.

The correction is negative or positive depending on whether the bow of the LNG carrier is deeper in the water or otherwise. In this illustrative case the correction will be negative.

3.2. INSTRUMENTS AND METHODS FOR MEASURING THE LEVEL OF LIQUID IN THE LNG CARRIER'S TANKS

3.2.1. Main liquid level gauging devices

The main types of gauges are:

- electrical capacitance type gauge,
- float type gauge,
- radar type gauge,
- laser type gauge: a recently developed system.

Currently ISO 18132-1:2011 and ISO 18132-2:2008 are valid for the above-mentioned level gauging devices.

Any of these gauging systems can serve as main instrument for liquid level measurement inside an LNG cargo tank. Usually (but not always) two or sometimes even three types of the above-mentioned systems are installed in each cargo tank of the LNG carrier. One of these should be agreed as the main (primary) level gauging device by buyer and seller. The standby or back-up gauging system(s) is (are) to be considered as the auxiliary (secondary) gauge systems.

A few LNG shipping agreements do not specify the type and only specify the required accuracy (e.g. ± 5.0 mm or better). On old ships other systems may be found, such as nitrogen bubbling devices, but the accuracy of these is generally lower and requires a good knowledge of the actual LNG density in the cargo tank.

Accuracy may be verified at the time of gauging, as follows:

- for electrical capacitance type gauges, by an on-line validation system,
- for radar type gauges, depending on the design, either by a verification pin or by comparison with the determined length of each still pipe segment,
- for float type gauges, either by comparison with the other gauging system or the stowed/grounded instrument’s level readings.

For the measurement of liquid levels in terminal berths exposed to the open sea, filtering systems approved and accepted by sworn surveyors as suitable to be integrated in CTS operations may be considered. These filtering systems were specifically developed for offshore use where large level fluctuations may be experienced. ISO 10976:2012 includes information on these systems.

3.2.1.1 Electrical capacitance type level gauge

The electrical capacitance gauge (see Figure 3) consists of two concentric tubes made of aluminium or stainless steel, depending on the construction of the LNG cargo tank. The inner tube is supported by the outer tube by means of concentric insulators placed at regularly spaced intervals along the whole length of the tubes. The resulting assembly forms a series of cylindrical capacitors, having the same total height as the cargo tank of the LNG carrier.

The LNG, according to its level, will fill the space between the concentric tubes. The liquid affects the dielectric characteristics of the capacitors formed by the tubes such that, by measuring the change in capacitance, the height of the LNG in the annular space, and hence the level in the tank, can be determined. The contraction of the tube assembly at low temperature may be taken into account to correct the level measurement.

The accuracy of the measurement resulting from the calibration of the dimensions and the linearity of the capacitor and of the electronics should be, for the gauge as a whole, ±5.0 mm [1].

3.2.1.2 Float type level gauge

Measurements are made with a float hanging on a tape or a ribbon (see Figure 4). According to the level of the liquid, the float is displaced, and the tape or the ribbon on which it hangs is unrolled or rolled up on a drum whose rotation is recorded. This enables the position of the probe, and thus the level of liquid in the tank, to be known.

With float gauges, it is necessary to take into account the shrinkage of the ribbon, according to the temperature of the gaseous phase and the height of the liquid, and the density of the LNG, which will influence the float buoyancy. The correction tables will tabulate the corrections for these effects.

The corrections for temperature are required only in the case of a stainless steel ribbon. In the case of an invar ribbon, the shrinkage is much less and is generally considered as negligible.

The accuracy of this type of gauge, designed for marine application, is in the range of ±4 mm to ±8 mm.

3.2.1.3 Radar (microwave) type level gauge

The radar or microwave type gauge works on the same principle as a ship's radar (see **FIGURE 5**). A transmitter/receiver is mounted on the top of the cargo tank and emits microwaves vertically down towards the surface of the liquid. The signal is reflected from the surface, received by the transmitter's antenna and sent back to the control panel. The signal is then processed to determine the distance of the liquid surface from the transmitter and hence ullage. One or more certified transmitters/ receivers are usually carried as spares in the event of a failure of this equipment.

Since all the level detection components are mounted external to the cargo tank, the microwave system allows for the possibility of changing the gauge in service.

The radar gauge requires a wave guide which is like a stilling well. However, this well is a critical and complex component resembling a gun barrel.

There are several types of gauging pipes used for microwave type CTS level gauges. Particular attention should be paid to bottom attenuators, which can limit minimum gauging height and therefore accuracy due to their mountings.

The accuracy of this type of gauge can be ±5.0 mm or better.

3.2.1.4 Laser type level gauge

The laser based sensor technology (LIDAR) is a recently introduced gauge type (see Appendix 2).

The laser unit is installed above the deck, isolated from the tank by a sight glass and targeting the liquid level surface with a low power laser beam. This beam is protected from adverse influences on its measurements arising from within the tank by an ordinary stilling well. The stilling well used on a laser based system is not used as a wave guide, its construction is simple and it remains relatively inexpensive.

The time interval between the transmitted and received pulses is accurately measured and processed to determine the distance of the liquid surface from the transmitter and hence the ullage height.

The level measurement remains unaffected by changes in the LNG composition or by the changes in physical properties of the still pipe. When performing level measurements at the bottom of the tank, echoes or reflections near the bottom do not affect the accuracy of the system. The gauge will also register a dynamic change in the LNG level. The accuracy of this type of gauge is ± 7.5 mm or better.

3.2.2. Timing of the level measurement

General guidelines are described in the standard ISO 6578 – Refrigerated hydrocarbons liquid – static measurement – calculation procedure.

It is important that the level readings are recorded in a static and closed condition of the LNG carrier, with no flow of either gas or liquid.

As far as practicable, the period between the time of measurement and start of cargo transfer should be narrowed to the minimum achievable. The same should apply for the final cargo custody transfer level measurement, once time is allowed to correctly drain cargo lines (as appropriate) and stabilize the liquid levels. The same temperature and inventory condition of the ship's LNG cargo lines should be maintained during both opening and closing custody transfer surveys. Wherever it is intended that the vessel heels out (is completely emptied) and cargo lines are empty upon completion of discharge, it is necessary to ensure that the cargo lines are drained for sufficient time prior to the closing CTS, to ensure stabilization of the temperature of the lowest temperature sensor.

3.2.3. Readings

It is good practice that all readings are witnessed by both parties, buyer and seller. Each party should appoint a representative. A sworn surveyor may also be jointly nominated by both parties to stand as third and neutral party, and witness and record the CTS readings.

The readings of the levels of liquid in the tanks are taken after the readings of the list (port or starboard), and the trim (bow or stern) of the LNG carrier. All these readings will be taken into account in order to determine the corrected liquid level and hence the LNG volume in each of the cargo tanks. The temperatures of the liquid and the gaseous phase are also measured (see Section 4.1 and Section 4.2). The absolute pressure in each LNG cargo tank is measured as well. If the pressure measurement is gauge instead of absolute, the atmospheric pressure is also read.

Parties should also agree in advance what actions are to be taken in the event of a failure of any part of the volume measurement system (e.g. consider secondary level gauging, manually calculate volumes with tank tables, etc.).

3.2.3.1 Reading of the level with float gauges

It is good practice that all float gauges are lowered to the liquid level well before any reading is taken. This should allow for sufficient time to cool down either the gauge ribbon or wire and to ensure shrinkage, if any, is stabilized. It is also good practice to verify that the calibration seals on the float gauge unit are intact.

Float gauges normally have two reference readings, upper and lower. The upper reading can always be checked. Depending on the manufacturer, this corresponds to a locked position of the float gauge in its stowed condition or a resting position of the float on the valve's isolation gate. These reference readings are reported on the ship's CTS calibration certificate and they are also stamped on a plate fixed to the gauge itself. It is advisable that the upper reference is checked before the cargo tank liquid levels are taken.

The cargo liquid level is never still and a slight movement of the float is always to be expected. Even when the ship is not subject to any wave motion, the readings will always be an average level between upper and lower peaks of level readings.

If no fluctuation of the liquid level is detected, this may indicate a possible "sticking" of the float inside the gauge well. If this is the case, it is recommended that the float is moved up and down a number of times in order to free it and obtain reliable readings.

On occasions when the LNG carrier's tanks are completely empty, the lower reference of the float can also be checked for correctness. This is usually called the float's grounded position.

Whenever remote float readings are available in the ship's control room, it should be checked that these are approved for commercial transactions before they can be used for CTS purposes. Float gauges are always stowed in their fixed upper position when sailing so that the ribbon or the tape does not break due to liquid movements.

3.2.3.2 Reading of the level with capacitance and radar gauges

The methods of reading are normally agreed between the seller and buyer. Usually the observed cargo tank level is averaged over 5 readings taken at specified and regular intervals.

The above method may not be suitable for LNG terminal berths exposed to the open sea because of the high fluctuations of the liquid levels. To cope with this, some custody transfer measurement systems manufacturers have lately developed filtering systems in order to average the level fluctuations and provide a realistic liquid level (see Section 3.2.1).

Level readings are normally available in the ship's cargo control room and sometimes in an instrumentation room located in the accommodation block.

Some modern on-board CTM systems use computer to process all the information, including averaging the (5) level readings over time, temperature and pressure, and draw on digital gauging tables to produce a printed document containing all the ship-generated information required for the custody transfer. However these seldom include "gas displaced" or "gas to engine room", if applicable.

3.2.4. Correction of readings

3.2.4.1 Float gauge

The readings made on the measurement appliances should be corrected according to:

- list,
- trim,
- density of LNG, affecting float buoyancy,
- coefficient of contraction of the material and the insulation of the tanks; this coefficient is more relevant in the case of self-supporting tanks (see Appendix 4, table A4-4),
- temperature of the gaseous phase if the ribbon or cable is not made of invar.
- standard and fixed corrections if applicable.

The corrections are made using specific tables for each of the above corrections.

3.2.4.2 Capacitance, radar and laser gauges

In this case, only the corrections for list, trim and the contraction of the tanks are normally taken into consideration. For accurate level measurement the contraction of the capacitance gauge at low temperature may also need to be considered.

Two main types of radar (microwave) gauges are currently available. One type is based on the principle of estimated velocity of the microwaves inside an atmosphere of predetermined hydrocarbon composition. Within the worldwide range of commercially-available LNG compositions this has little impact on the overall accuracy of the gauge except for nitrogen content in the vapour which may significantly alter wave velocity and should be considered.

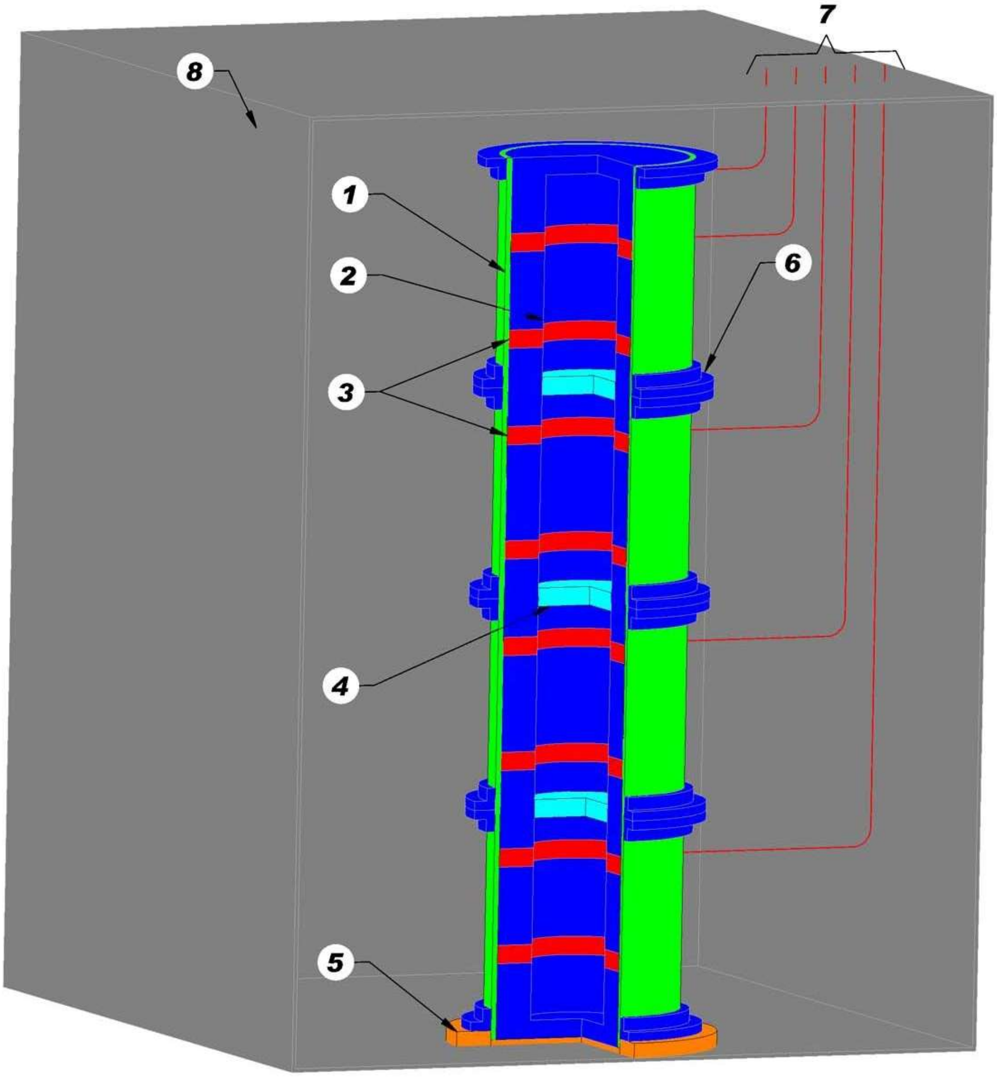
One available type of microwave gauge uses several defined targets made of PTFE (Teflon ®) at known positions along the stilling pipe. This enables the system to precisely calculate the microwave propagation speed and adapt it to locate the liquid level. The PTFE target position is usually known at +20°C. In order to determine the wave propagation speed, the position of the targets is corrected according to the shrinkage of the still pipe, which is calculated as a function of the vapour phase temperature above the liquid level.

As to correction of readings for laser gauges, please refer to Appendix 2.

Modern computer-based systems usually can accept trim and list data either manually or from external sensors and automatically apply the corrections. However, it is important to compare the observed trim/list to the data from the trim/list independent sensor.

Depending on the sensor's location, either sagging or hogging of the LNG carrier may seriously affect the accuracy of the readings.

FIGURE 3: ELECTRICAL CAPACITANCE TYPE LEVEL GAUGE



1. Outer tube
2. Inner tube
3. Concentric electrical insulator
4. Isolation of inner tube sections by a gap or dielectric plug
5. Isolation from the tank bottom
6. Connections between the sections of the outer tube to make a single electrical conductor.
7. Data signal connections from the gauge to the junction box outside the cargo tank
8. LNG cargo tank

FIGURE 4: FLOAT TYPE LEVEL GAUGE

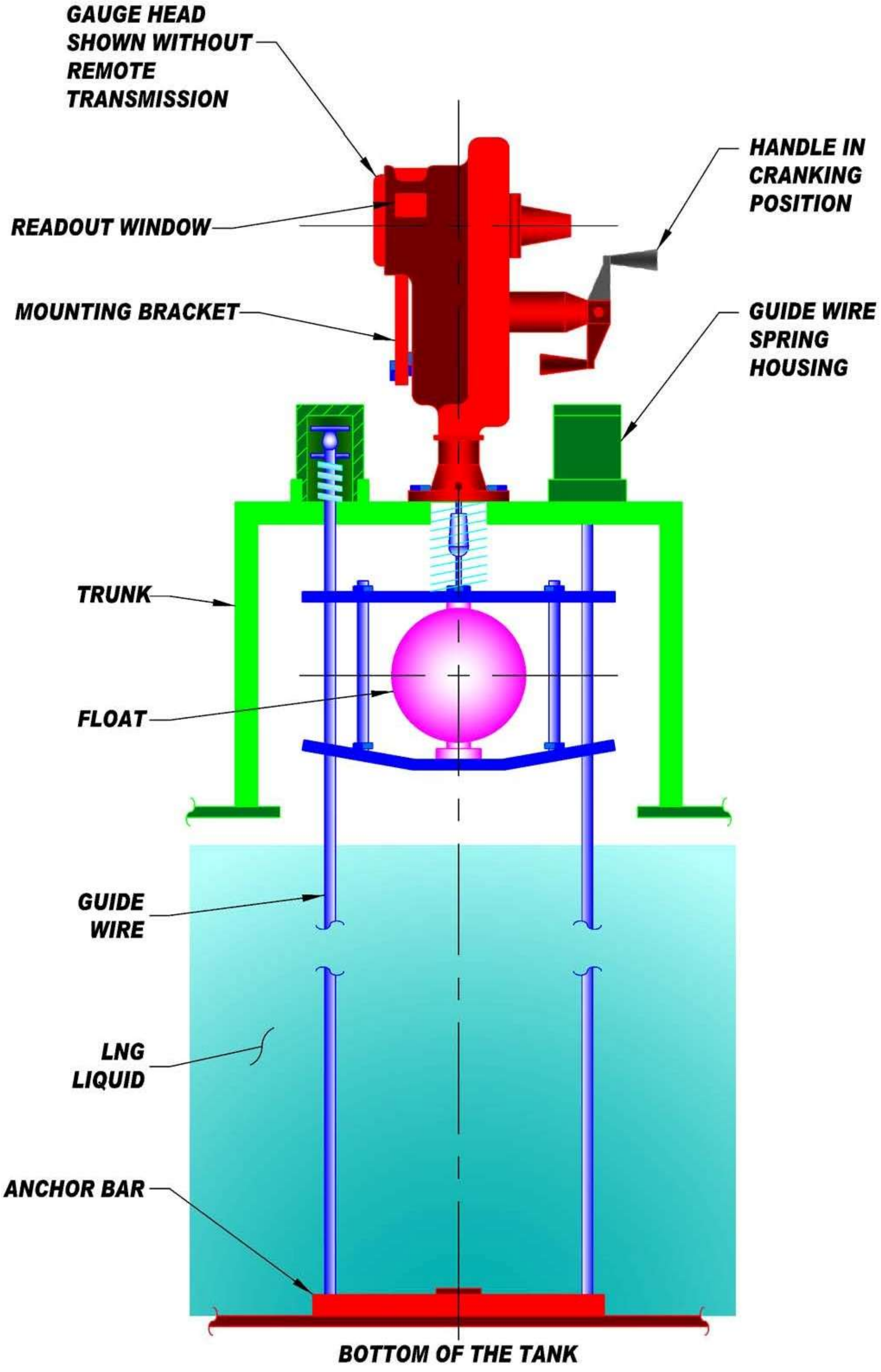
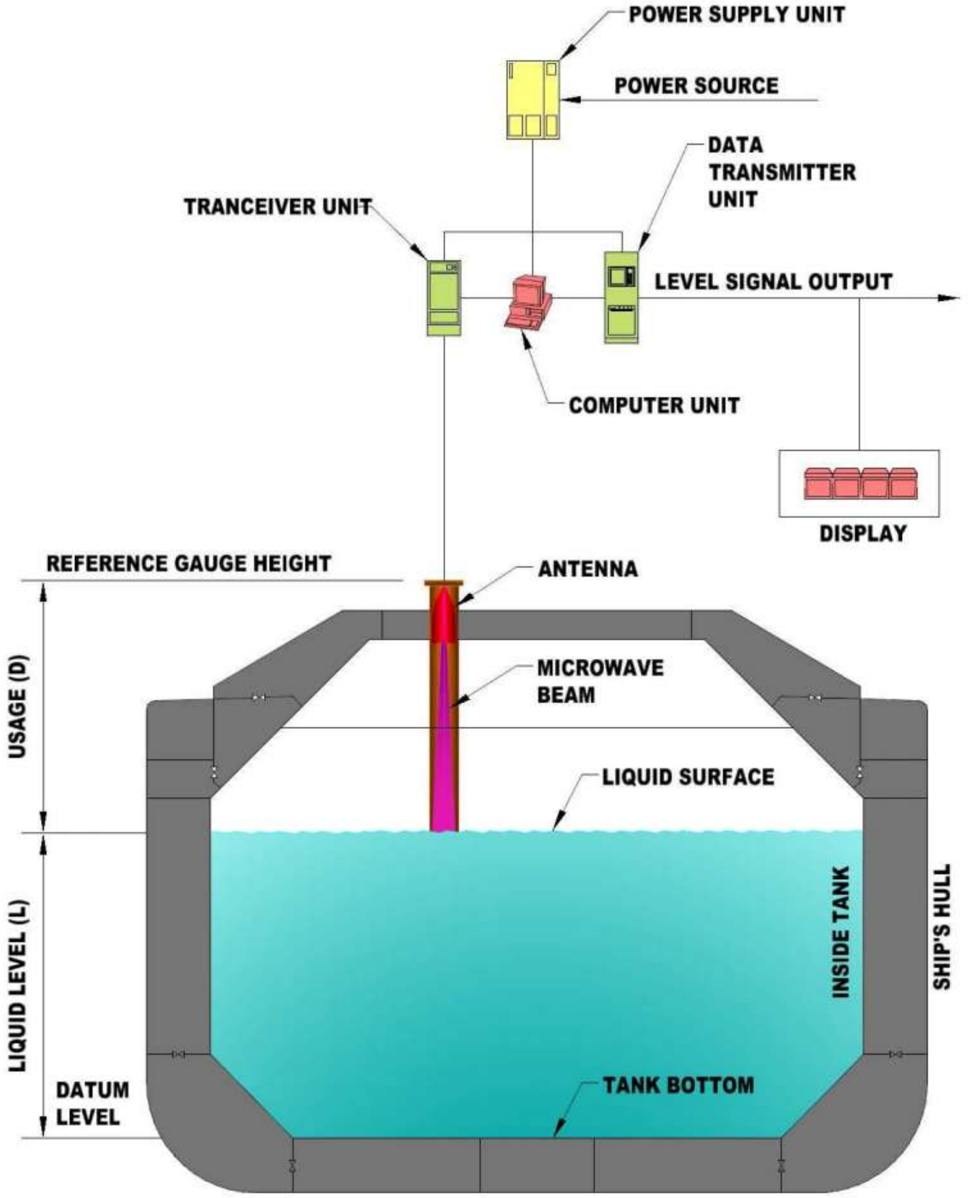


FIGURE 5: RADAR (MICROWAVE) TYPE LEVEL GAUGE



3.2.5. Use of spare level gauge

When the main or primary level gauge cannot be used, the spare level gauge, also called the secondary level gauge, is used to measure the level of LNG. Therefore it should always be in operation. Usually, the secondary level gauge will also be calibrated and certified. However, if the calibration tables of the LNG carrier are available only for the main level gauge, a conversion table is required in order to take into account the respective locations of main and secondary gauges, or the statistical differences between the two level gauge measurements, and to evaluate the corresponding corrections which must be applied to level measurement before using the calibration tables.

Since it is possible that the primary level gauging system could fail during the cargo transfer operation, and since it is strongly recommended to use the same reference system at both opening and closing CTS measurements to determine the cargo volume transferred, it is therefore advisable that both primary and auxiliary level gauging systems readings are recorded at the opening CTS measurement, before the start of cargo transfer operations. It should also be ensured that the spare level gauge is maintained within stated accuracy at all times.

3.2.6. Complete unloading (tank stripping)

Cargo tank stripping with stripping pumps:

- the LNG carrier needs to be able to continue discharging once the cargo pumps cannot longer be kept running because the level in the cargo tank is too low,
- these stripping operations require several additional hours at the port. Stripping to lowest levels is generally conducted prior to scheduled dry-docking or for spot cargo operations,
- the remaining quantity after stripping can be vaporised by warming up to a temperature at which the LNG carrier is considered to be empty of LNG. e.g. -80°C (no more liquid ethane) or -40°C (no more liquid propane). The vaporization of residual LNG is typically conducted not at berth but at sea, after the unloading is finished and the vessel has left the berth.

For the complete or nearly complete unloading of an LNG carrier with prismatic tanks, depending on the membrane type, the ship should be trimmed to the best condition to achieve effective stripping and a reliable level reading at the end of operations. In general, LNG carriers with prismatic tanks require the ship to be trimmed by stern in order to achieve complete or nearly complete unloading of cargo. Depending on the membrane type, higher trim levels will also result in more effective cargo tank stripping provided that care is taken not to exceed neither ship nor Terminal limitations, if any in place. Whatever the primary membrane configuration, some LNG liquid will, however, always remain in the cargo tank and that needs to be quantified. It is essential that, as much as possible during the stripping operation, the liquid level is always within the certified minimum gauging height. e.g. using onboard CTMS or cargo tank tables using appropriate correction tables. In the event the liquid level falls outside the certified minimum gauging height, buyer and seller should agree on the immeasurable cargo quantity.
The energy of this remaining LNG transferred either in the liquid or in gaseous form can also be determined by mutual agreement by the parties taking into account any technical limitations they may have.

> **Note**
> Certain parties have raised concerns over the possibility of having a quantity of LNG unaccounted for during closing of CTS under a positive trim as a result of LNG being trapped in the bottom part of uncovered corrugations of MARKI/MARKIII membrane systems, where small liquid wedges may form between the tank's bottom plate and the transverse corrugation in each of the exposed tank's bottom cells. The validity and extent of such liquid entrapment is currently unknown. This will require further and full investigation by independent and expert parties, before any conclusion can be made on the subject. The conclusion of such investigation should then be fully endorsed and certified by independent and recognized sworn surveyors.

3.2.7. Automated systems

The LNG carrier may be fitted with an automatic system for the calculation of LNG and gas volumes in each tank. The use of such a system, commonly referred to as the ship's custody transfer measurement system (CTMS) will facilitate the process of determining quantities transferred during loading and unloading.

The CTMS processes data from tank level, temperature, pressure sensors, etc. in real-time, taking into account the required corrections and certified gauge table, to produce a calculation of volumes before, during and after transfer. By taking measurements frequently, data can be averaged to improve repeatability of the calculation.

Modern custody transfer measurement systems typically comprise two discrete parts: (a) the tank gauging system providing corrected tank levels, temperatures and pressures and (b) workstation(s) and peripherals, usually located in the ship's cargo control room, to perform the volume calculation and generate reports.

Prior to such systems being entered into service, the calculation, including corrections and gauge tables programmed into the system, should be certified as accurate by an independent and competent third party, see Section 3.1.3. Once the software has been verified, the calculation method may be regarded as reliable so long as the software is unchanged. Software modification may necessitate re-certification. It should also be recognized that the sensors have to be recalibrated at agreed intervals to ensure that input data is accurate, see Section 2.3.5.

Custody transfer measurement systems may be capable of correcting for trim and list both manually (by operator input of draught readings) and automatically (by sensor data). The method should be agreed between buyer, seller and terminal operator. Trim and list sensors cannot be readily recalibrated once in situ so manual methods are often preferred. Due attention should be given to the proper location of the trim/list gauges on board the vessel. If due to an inappropriate location these gauges are influenced by the position of the vessel, this may affect the accuracy of the instrument.

It is appreciated that a software-based calculation may be less transparent to the buyer, seller and terminal operator than more traditional methods. The CTMS as a whole should be dependable in use. In addition to software verification, due regard should be given to hardware availability, reliability and maintainability to minimize the likelihood and consequence of failures in use.

It is recommended that instruments are connected directly to the system, i.e. sensor data cannot be manipulated by other systems unless part of the certified arrangement. Furthermore, computers (PC, process controllers), data communication links (serial, network) and peripherals (screens, keyboards, printers) should not, in general, be shared with other applications in order to maintain data integrity. However, a copy of the calculation software may be hosted on a shared workstation as a back-up to the primary system.

Data used in the transfer process, such as tank levels, may be transmitted from the CTMS to other ship's control and monitoring systems providing this does not influence the custody transfer calculation. In general, data should not be transmitted to the CTMS from other systems unless it is part of the certified arrangement.

Custody transfer measurement systems are typically able to produce printed reports indicating volumes before and after transfer. However, the ability to automate this part of the custody transfer survey does not obviate the need to provide, if required, the information required to carry out the calculation manually.

3.3. CALCULATION OF THE VOLUME OF LNG TRANSFERRED

This calculation is illustrated by an example given in Appendix 5 showing the results of the volume determination before and after loading the LNG cargo, with the following assumptions:

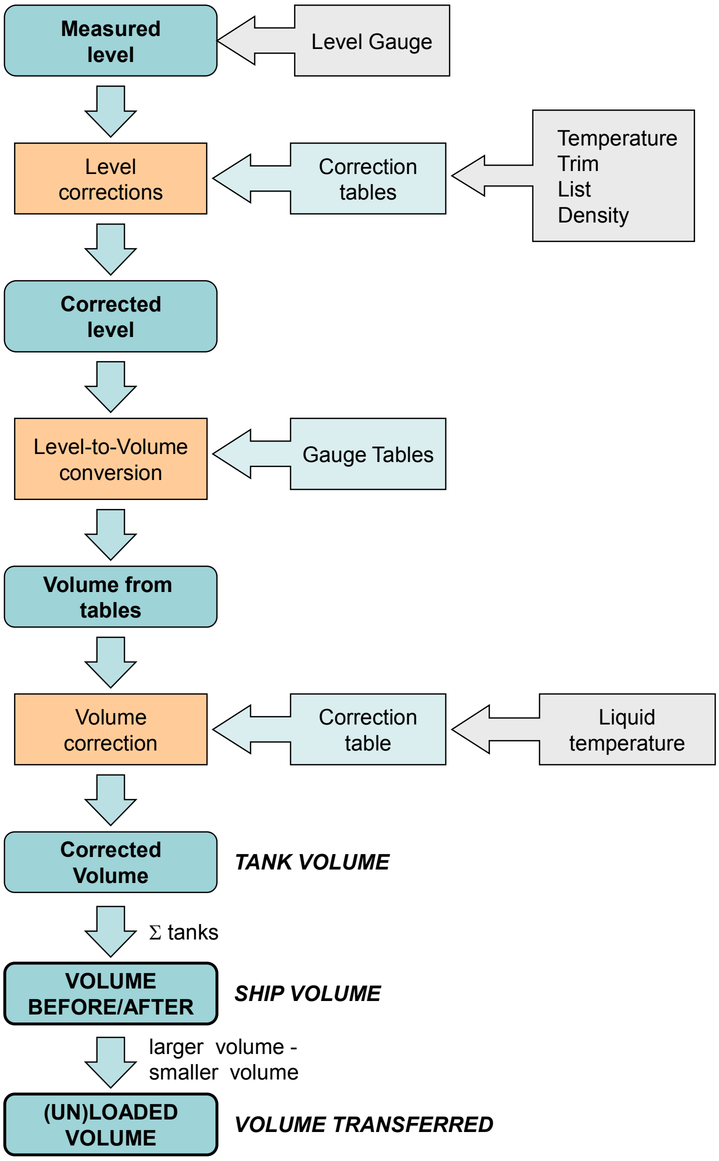
- a "Gaz Transport"-type LNG carrier with 5 invar membrane prismatic tanks,
- in each tank, one float gauge with a stainless steel ribbon.

The example as illustrated is representative of an LNG carrier with an older level gauging system. In order to calculate the volume transferred, two conditions are required, knowledge of the total cargo volume on board (a) before the start of cargo transfer operations and (b) after these cargo transfer operations are completed. These two conditions are either manually recorded or directly produced and printed out by a computer if available. Details of each cargo tank parameters must be logged. In order to document a cargo transfer operation, modern primary custody transfer measurement systems produce three printouts, a so-called "before loading/discharge" cargo tanks status, an "after loading/discharge" cargo tanks status and a third printout just after the "after loading/discharge" condition; which is usually referred to as the "Certificate of Loading/Discharge". This third printout summarizes the general parameters of the two conditions and shows the volume transferred by comparing the initial and final cargo volumes. An example of Custody Transfer Survey documents for an unloading of an LNG vessel is given in Appendix 15.

It is essential that the LNG carrier's pipework and manifolds are kept as far as practical in the same inventory condition at the opening and closing Custody Transfer Surveys.

Figure 6 illustrates the calculation procedure to determine the volume of LNG transferred based on the ship's measurements.

FIGURE 6: FLOWCHART FOR DETERMINING THE VOLUME OF LNG TRANSFERRED



4. TEMPERATURE MEASUREMENT

4.1. LIQUID TEMPERATURE

4.1.1. Device

The LNG temperature is measured by probes placed at different heights in the tanks. These probes are generally three- or four-wire platinum resistance temperature sensors (usually Pt 100), of which there are typically five per cargo tank. Recently-built LNG ships often have also calibrated back-up sensors fitted next to each main thermal sensor, which can be selected and used in case of main sensor failure.

One probe should always be in the liquid phase at the bottom of the tank and one always in the vapour phase at the top of the tank.

The tank gauge table also provides the vertical height of the location of the temperature sensors, so that it may be determined whether the sensor is in the liquid or in the vapour phase during custody transfer measurement.

The temperature measurement of these probes is converted into degrees Celsius with the help of a data acquisition computer equipped with a printer. Table 1 shows an example of a printout of LNG temperatures when the tanks are filled to 98% capacity with LNG.

Figure 7 shows a diagram of temperature measuring devices installed on a LNG carrier. In this example, five probes are immersed in LNG in each tank. A sixth probe (not shown) is in the vapour phase at the top of the tank.

The average liquid temperature is calculated upon the opening and the closing Custody Transfer

Surveys. The average liquid temperature is calculated using the temperature reading at each individual temperature sensor that is in the liquid, and not the average temperature of each cargo tank.

Thermocouples are not used for LNG temperature measurement within custody transfer because they are less sensitive at very low temperatures and often give a less accurate measurement than platinum resistance probes. In addition their installation is more complex requiring compensation cables. They may be installed sometimes for control or simple indication purposes such as cooling down or heating of the tank.

4.1.2. Testing and accuracy

The accuracy of the platinum resistance thermometer varies between ±0.1 and ±0.2°C for temperatures ranging between -145 and -165°C. The overall uncertainty of the temperature measuring chain can be estimated at about ±0.5°C (including sensor, cable, signal converter, display).

The sensors are tested for accuracy at the manufacturer's facility prior to installation, and certified/calibrated upon installation in the cargo tanks. The temperature measurement is tested and recalibrated at regular intervals to ensure continued performance.

The influence of temperature measurement accuracies on the determination of LNG density (see Section 15) is important. For instance, for LNG with an average density in the range 440 - 470 kg/m^3, and at a temperature around -162 °C, the relative accuracy in density calculation, due to an accuracy of 0.5 °C in temperature measurement, is about 0.15 %.

4.2. VAPOUR TEMPERATURE

The temperature in the gaseous phase of the tanks is used to determine the quantity of gas displaced during the loading and unloading operations, or the level correction of the float gauge due to ribbon shrinkage.

As for liquid temperatures, the average vapour temperature is calculated using the temperature reading at each individual temperature sensor, and not the average temperature of each cargo tank. However, only temperatures indicated by probes not immersed in the LNG are averaged in this case.

Typically an accuracy of ±1.0 °C (in the range –145 to +40 °C) is required.

5. VAPOUR PRESSURE MEASUREMENT

Vapour pressure measurements can be made with a pressure gauge, which indicates the pressure in the gas spaces of the cargo tanks.

This pressure is needed to calculate the energy of displaced gas, see Section 12.1. For this, it is necessary for the pressure to be in absolute terms. If the ship's instrumentation measures pressure in 'gauge' terms, then the atmospheric pressure must be recorded and added to the gauge pressure.

The pressure value is recorded, with the atmospheric pressure if appropriate, at the time of taking the other CTS readings.

Typically the required pressure measurement accuracy is specified as between ±0.1 and 1 % FS (% of full-scale instrument range).

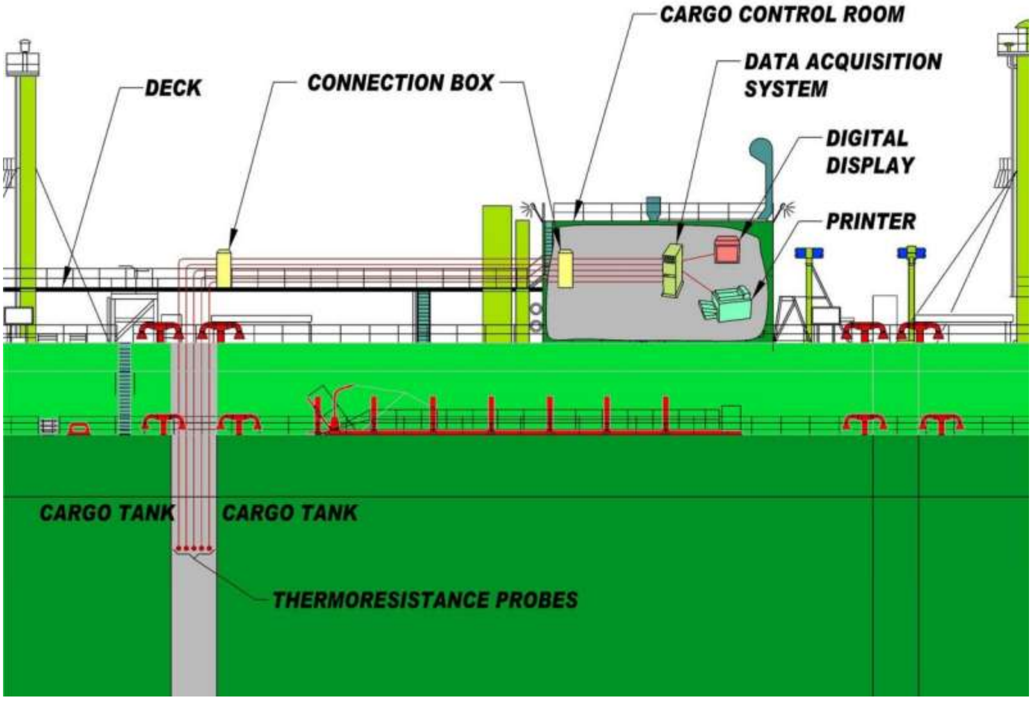
ISO 10976 also addresses vapour pressure measurement.

TABLE 1: EXAMPLE OF TANK TEMPERATURE RECORDINGS (98 % FILLED)

TEMPERATURE PROBE	TANK 1 °C	TANK 2 °C	TANK 3 °C	TANK 4 °C	TANK 5 °C
T 1	-161.83	-161.90	-161.94	-161.89	-161.84
T 2	-161.80	-161.88	-161.91	-161.89	-161.86
T 3	-161.82	-161.87	-161.92	-161.90	-161.90
T 4	-161.79	-161.86	-161.87	-161.88	-161.81
T 5	-161.82	-161.82	-161.88	-161.91	-161.84
TANK AVERAGE	-161.81	-161.87	-161.90	-161.89	-161.85

The liquid temperature in each tank is determined by the arithmetic average of temperatures indicated by the probes that are dipped in the LNG and that are in working order.

FIGURE 7: DIAGRAM OF TEMPERATURE MEASURING DEVICES ON BOARD A LNG CARRIER



6. SAMPLING OF LNG

6.1. LNG SAMPLING PRINCIPLES

In order to determine the quality of the LNG it is first necessary to undertake particular operations to condition the fluid sampled from its initial state, liquid at low temperature, to a final state, gas at ambient temperature, without partial vaporization or loss of product.

Sampling of LNG includes three successive operations:

- taking a representative sample of LNG,
- complete and instant vaporization,
- conditioning the gaseous sample (e.g. ensuring constant temperature and pressure) before transporting it to the analyzer and/or sampler.

Sampling is the most critical point of the LNG measurements chain. Each step must be taken without changing the sample composition. This is by far the most complicated phase of the measurements and most of the problems observed in determination of the energy loaded or unloaded come from the sampling system. The sampling system is not changeable during unloading/loading. Some operators have a back up sampling system to ensure sample collection in the event of failure of the main system.

The LNG industry has evolved the sampling processes. The "spot (discontinuous) sampling system" described in the first edition of this handbook has become almost obsolete for CTS measurements. It is therefore recommended to use this only as a back-up system in case of failure of the main device. The spot sampling system may be used, however, for the (manual) sampling for impurity analyses. For completeness, description of this system is given in Section 6.9.

The sampling processes currently used in the LNG industry are mainly of two types; continuous sampling and intermittent sampling, both sampling processes as defined in ISO 8943. The intermittent sampling is also referred to as discontinuous sampling in other publications such as the EN 12838 standard and the current GIIGNL handbook. Please note that the terminology continuous/discontinuous is different from that used in the first and second edition of this handbook.

The terms continuous and discontinuous sampling are related to the analysis of gaseous LNG, that is, after evaporation of the sampled liquid stream. LNG sampling systems always sample LNG on a continuous basis:

- **continuous sampling**:

  This sampling process involves continuous collection of LNG from the LNG flow line during the loading/unloading operations. The regasified LNG from the vaporizer is thereafter continuously fed into the gas sample holder. Gas sample containers (definition according to ISO 8943) are filled with the mixed gas from this gasholder after completion of the sampling process for offline analysis.

  discontinuous sampling: (referred to as intermittent by ISO 8943) This sampling process also involves continuous collection of LNG from the LNG flow line during loading/unloading operations. However, the regasified LNG from the vaporizer is in this process partly directed to an on-line GC and partly into a constant pressure floating piston (CP/FP) sample container (definition according to ISO 8943).A CP/FP sample container is capable of maintaining constant pressure during the sampling of gas from the process line into the gas cylinder. The gas sample collected in the CP/FP sample container is for offline analysis.

European Standard EN12838 specifies tests to be carried out in order to assess the suitability of these two LNG sampling systems. However, this EN standard was published before the current version of ISO 8943 and actually refers to the previous version of this ISO standard. The most important difference is that the discontinuous process described in the EN 12838 standard is replaced by the intermittent process in ISO 8943. The discontinuous method directs all sample gas to the on-line GC while the intermittent process in addition includes a method to fill sample CP/FP containers. This allows for retained sample analysis.

Current LNG sampling systems in operation deviates from those in the standard and cause confusion whether the system can be described as continuous or discontinuous.

The LNG sampling devices shall be such as to ensure the total and continuous vaporization of a quantity of LNG. This quantity must be sufficient for taking gaseous samples representative of the LNG being (un)loaded.

Most LNG terminal ship unloading lines (and LNG production plant loading lines) have two main operating modes:

- circulation of LNG from the storage tanks when there are no (un)loading operations,
- LNG Carrier (un)loading.

The operating pressure can be quite different in each operating mode.

The sampling system should preferably be designed in such way to assure representative vaporization even during the lowest LNG line pressure. Sub-cooling (see ISO 8943, annex A) of LNG up to the vaporizer should be ensured at all times when the system is used for heating value determination of the LNG. This could require vent gas flow adjustment between changes in operating mode or vaporizer setting adjustments (temperature, power). Lowering the static pressure should be carried out very prudently to avoid adverse (e.g. geysering) effects in these long lines.

6.2. SAMPLING POINT

The sampling point is generally located:

- on the main loading pipe (line), after the LNG pumps send-out,
- on the main unloading pipe (line), after the unloading arms.

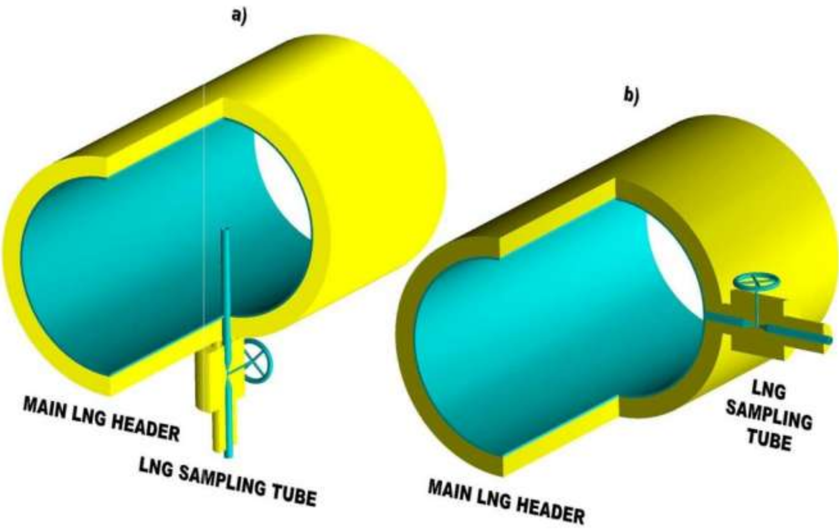
LNG must be sampled during a stable flow of LNG. It is preferable to install the sampling point as close as possible to the custody transfer point (loading arm flange/ship manifold or main header) so that the characteristics of LNG do not change before it is actually transferred because of potential heat input. However, generally the influence of heat input is limited, when the flow does not vary too much in the properly insulated main unloading/loading line.

Again, please note that the LNG **must** arrive in a sub-cooled condition at the sampling point/vaporizer. The LNG sub-cooled condition can be determined by using the method proposed in ISO 8943 (annex A). If this is not ensured representative sampling is likely to fail.

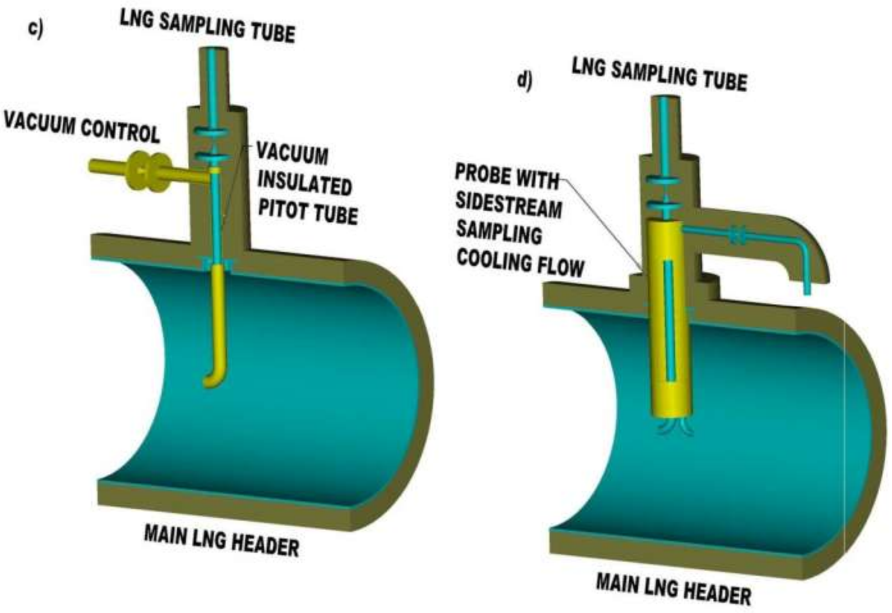
6.3. SAMPLING PROBES

FIGURE 8: EXAMPLES OF SAMPLING PROBES

Direct connection on main LNG line (cross section view)



With a Pitot tube (transverse section view)



In order to keep the LNG sampling flow in a sub-cooled condition, the ambient heat input should be minimised. The following lay-outs can be used:

- a straight sampling tube inside the main LNG header (Figure 8a),
- a direct connection on the periphery of the main LNG header by appropriate insulation around the sampling tube to reduce the ambient heat input to the main pipe (Figure 8b).

Remark: both above lay-outs require appropriate insulation around the sampling tube, sample stream can be further minimised by an (optional) permanent external side-stream LNG flow to a purge line of the plant.

Improved sampling systems use Pitot tubes. They can have:

- vacuum insulation around the Pitot sampling tube (Figure 8c) completed with appropriate insulation of the top part of the probe,
- an LNG Pitot sampling tube cooled by a permanent internal side stream flow initiated with natural LNG circulation going back to the LNG header (Figure 8d).

6.4. PIPING ARRANGEMENT BETWEEN SAMPLING PROBE AND VAPORIZER

It is important to have the liquid sample line, between the sampling probe and the LNG vaporizer, as short as possible, with a small inside diameter (1 or 2 mm for instance) and with sufficient insulation, so that the LNG is kept in a sub-cooled condition until it reaches the vaporizer, and this for all possible (un)loading conditions including recirculation at low pressures.

The maximum recommended length of the liquid sample line between the sampling point and the vaporizer can be calculated using the following formula:

$$l = \frac{W.\Delta H}{q}$$

where:

l = the length of pipeline (m)

W = the flow rate of sample LNG (kg/s)

ΔH = the degree of sub-cooling at inlet of sample probe (J/kg)

q = the heat input (W/m)

In calculating this maximum length of the pipe, the value of q is the most difficult value to estimate accurately. The value chosen should be larger than the design value to take into account the ageing of the insulation.

6.5. LNG VAPORIZER AND CONTROL DEVICES

6.5.1. Main devices

The vaporization of the LNG must be as complete as possible, so that the gas obtained is truly representative of the quality of the LNG.

The vaporizer must be designed in order to avoid fractionation. To that effect heating to a sufficiently high temperature, e.g. 50°C, is required to ensure immediate vaporization of even the heaviest trace components. A proper sampling conditioning system (accumulator) should be installed to minimize possible effects from pump pulsation, fractionation and condensation.

Vaporization of sampled LNG is commonly achieved by direct electrical heating. Alternatively heat exchange with water may be used which is heated electrically or by steam. These devices are described in more detail in Sections 6.5.1.1 and 6.5.1.2.

Open tubular atmospheric vaporisers in which the heat comes from the ambient air have been used. However, the heat flow may not be enough to avoid fractionation of the sampled LNG and the use of these devices is submerged, or steam warming the coil up directly (Shell & tube LNG Sample Vaporizer). This is considered out-dated and is not recommended.

6.5.1.1 Electrical vaporizer

In an electrical vaporiser, the sampled LNG passes through an electrical-resistance heated regulator or, alternatively, through a tube which is heated electrically by induction.

FIGURE 9: EXAMPLE OF ELECTRIC VAPORIZER

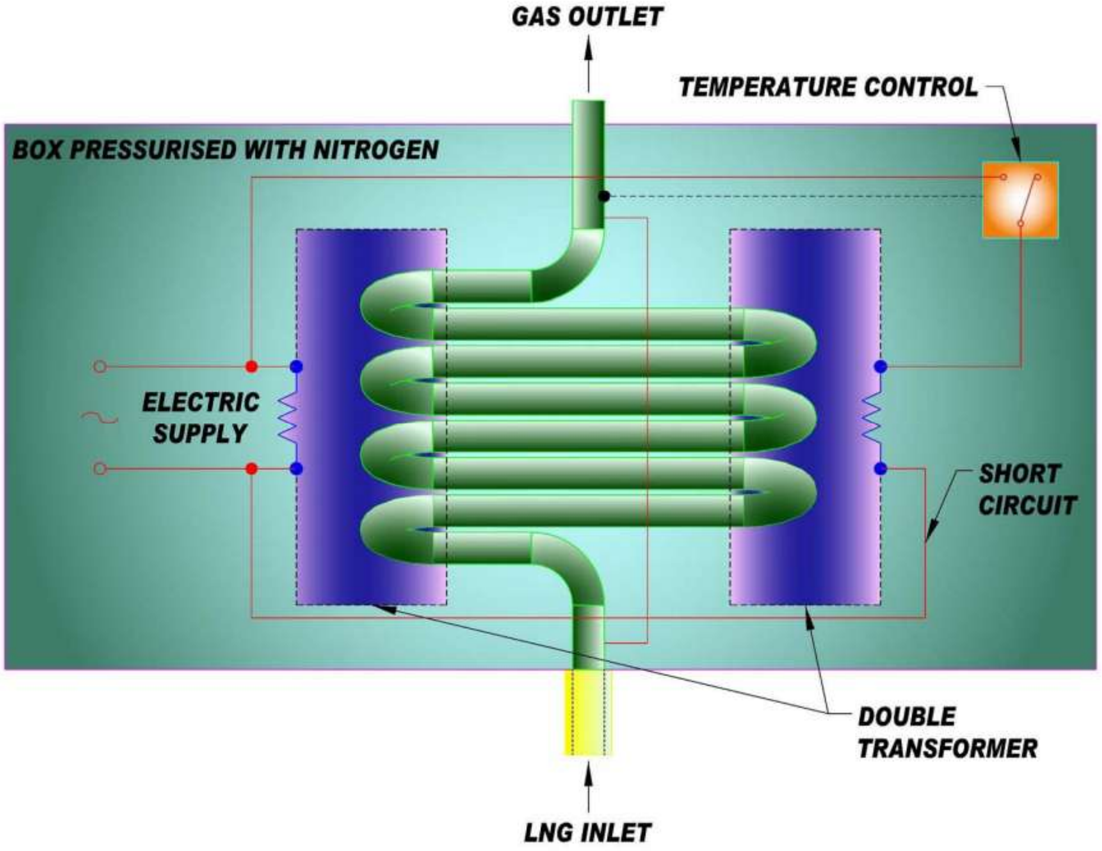
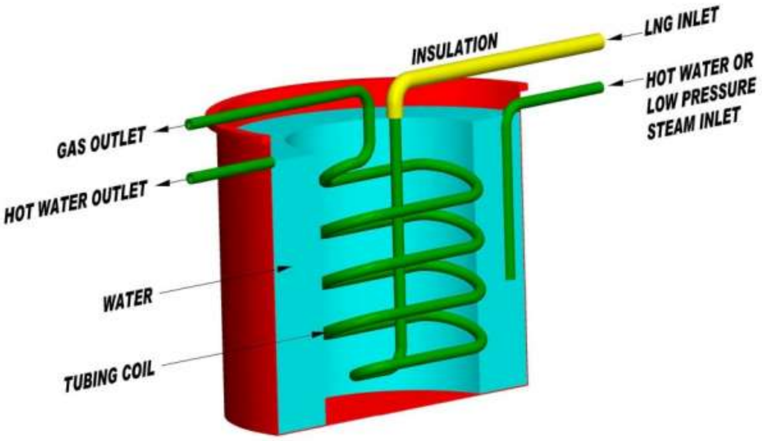
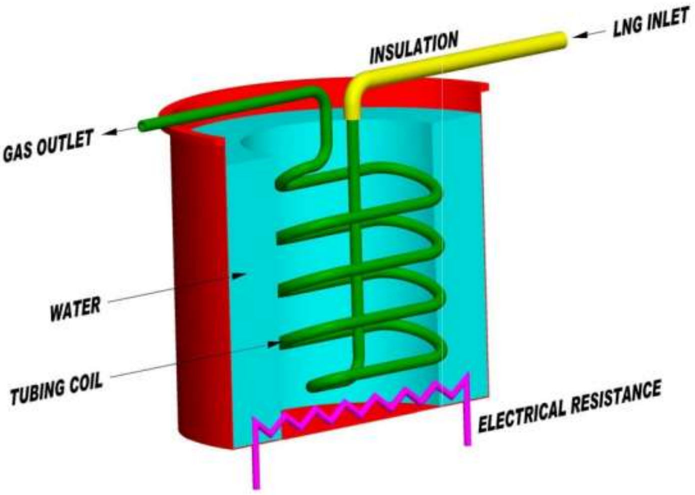


FIGURE 10: EXAMPLES OF WATER OR STEAM VAPORIZERS

a) With water or steam circulation



b) With water warmed by electrical resistance



c) Shell & tube type vaporizer

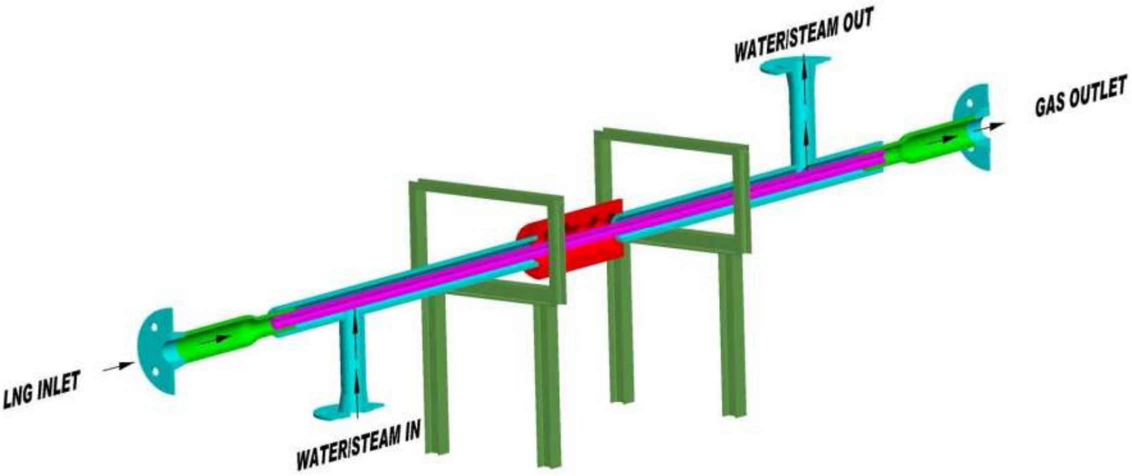


Figure 9 shows an example of an electric induction vaporizer which consists of an electrically conductive tube coil in which LNG flows and vaporizes, this coil being a secondary winding of a transformer. The primary winding of the transformer is supplied by electricity and the induced current that develops in the coil produces the energy necessary to vaporize the LNG sample flow. This heating principle is the only known EN 12838 validated sampling system. The tube coil can be made of copper or stainless steel. Stainless steel is recommended and is used in the new generation of electrical vaporizer.

6.5.1.2 Water or steam vaporizer

Figure 10a and Figure 10b show diagrams of vaporizers using water circulation (preferably hot water), or water warmed by steam as heating fluid, or water warmed by an electrical resistance submerged in the vessel, or by direct low pressure steam.

The LNG sample flows in a tubing coil installed in the vessel and vaporizes in it. The coil is usually made of stainless steel (recommended) or, sometimes, copper.

One form of steam vaporiser uses a shell & tube heat exchanger in which the sampled LNG flows through a tube surrounded with a steam or water-heated shell (see Figure 10c). This is considered outdated.

6.5.2. Auxiliary vaporization control devices

Control devices must be installed to supervise the conditions of vaporization of sampled LNG and to protect the equipment. They are typically installed as follows.

6.5.2.1 On regasified LNG outlet

- pressure regulator, or gas flow rate regulator, to control the LNG flow to be vaporised independently of pressure or flow rate in the main LNG pipe,
- anti-pulsation bottle, or mixing accumulator, to absorb the pressure pulses and to maintain gas homogeneity,
- impingement chamber, to prevent the entrainment of possible fine droplets of liquid,
- flow meters and / or flow limiters to control the maximum flow off take,
- pressure meters,
- temperature detection switches, in case of very high gas temperature (example: no more LNG flow) or very low temperature (example: failure of heating device),
- associated devices, such as overpressure safety valve, electro(magnetic) valve to isolate the vaporizer, etc.

6.5.2.2 On LNG inlet

- check valve or restriction orifice, to prevent a possible retro-diffusion of vaporised components to the main LNG pipe,
- needle valve, to control the flow of LNG (however, it is better to control gas phase flow in order not to disturb the state of the LNG sampled),
- filter,
- blocking valve to enable safe maintenance of the sampling system by isolation from the liquid LNG,
- a liquid bypass system to give full flexibility to the sampling system in case of maintenance.

6.5.2.3 On heating fluid (water, steam or electricity)

- temperature regulator, or thermostatic control, to keep constant vaporizing conditions according to the LNG flow,
- thermometer and thermostats in case of failure of heating devices,
- control of the electrical supply of the transformer or of the (submerged) resistance heating element.

6.5.2.4 Safety devices

Electrical supply and electrical equipment must be of a type designed for hazardous conditions (i.e. explosion proof). For example, the use of an enclosure pressurized with inert gas.

6.5.3. Operating parameters

The following operating parameters can be particularly recommended:

- sample pressure at the sampling point greater than 2 bars,
- vaporizer outlet temperature not below about +20°C. (in practice 50°C is often used as a set point),
- suitable sample flow rates as these depend highly on the kind of vaporizer used. (inductive heated vaporizers use about 1 m³(n)/h while electrically heated regulators use about 1500 l/h),
- sample data to be collected during a steady (un)loading rate. This means after ramping up, once full LNG (un)loading rate is reached, and before ramping down.

During sampling it is essential that the process conditions of the sampling system (flow temperature and pressure) remain in a stable and stationary condition. Sudden changes in gas off-take (for example due to the opening of a valve or the removal of a sample cylinder) that will affect the gas flow, should be avoided at all times. These changes can cause the gas to fractionate, resulting in improper sampling and fluctuation in measured heating value.

6.5.4. Gas sample collection systems

To collect either an intermittent or a continuous sample of the vaporized LNG generally two options are available.

A large gas holder (usually between 0.5 and 1 m^3) may be used to store a representative portion of the vaporized LNG during the transfer operation. The characteristics of the gas contained after completion and mixing is representative of the characteristics of the LNG loaded or unloaded. These gas holders can be of several types: water-seal type, the sealing water being saturated with gas by bubbling regasified LNG through it before filling the holder, (see Figure 11a) or waterless type with a bladder in the gas holder and a vacuum pump (see Figure 11b),

For intermittent sampling a pump can be used that delivers small portions of regasified LNG into a CP/FP sample container. The total amount of such portions depends on the transfer flow and total amount of LNG cargo being transferred. In this case the sample holder generally has a volume between 500 and 1 000 cm³ (see Figure 11c).

A third sampling principle that is also based on intermittent sampling is called spot sampling. With spot sampling an appropriate quantity of vaporized LNG is injected in a properly purged sample cylinder. When gas samples are taken in gas sample containers during LNG transfer it should be done with regular intervals, depending on the characteristics of the transfer lines and equipment, the organization of operation in the plant, the duration of gas sample analysis, etc.

Example: the common practice for spot sampling is to take samples during three events only: at 25%, 50% and 75% of loading/unloading operations.

6.6. GAS SAMPLE CONDITIONING

After the sampled LNG has been vaporized properly, there are two ways of transferring it for analysis: in gas sample container (definition according to ISO 8943: sample container used for the retention of the gas sample and for its transfer to an analyzing instrument)or by direct piping to a gas analyzer.

6.6.1. Gas sample containers

The containers are filled:

- either at the outlet of a gas sample line coming from the gas sample holder normally referred to as a dome sampler, possibly through a booster compressor or vacuum pump (continuous sampling, see ISO 8943) (see Figure 11a and Figure 11b),
- or directly, at the outlet of the vaporizer unit. Regasified LNG is fed at specified intervals into a CP/FP sample container during the transfer operation using sample pumps, normally referred to as a piston sampler (intermittent sampling, see ISO 8943) (see Figure 11c),
- or directly, at the outlet of the vaporizer unit, periodically during the transfer operation. This is referred to as spot sampling, and is not recommended.(Figure 11 a, upper part),

Gas sampling containers should have sufficient capacity for the analyses that follow, for instance 1 litre.

They are generally made of stainless steel and could be either with valves at both ends, as shown in Figure 10d or could be constant pressure floating piston containers (CP/FP sample container, as shown in Figure 11e.

In view of frequent handling of the containers, quick connectors are preferred over screw connectors.

After purging of piping has been performed, several containers may be filled simultaneously or successively (not preferred as it is very important to have the 2 or 3 bottles filled at the same time), according to the installed manifold. It is extremely important to take care that no air enters the container and that the container is sufficiently purged before taking the gas sample to be analyzed.

6.6.2. Direct piping to a gas analyzer

A Gas Chromatograph is directly connected to the vaporiser outlet to perform subsequent analyses during unloading or loading process providing a set of LNG composition data.

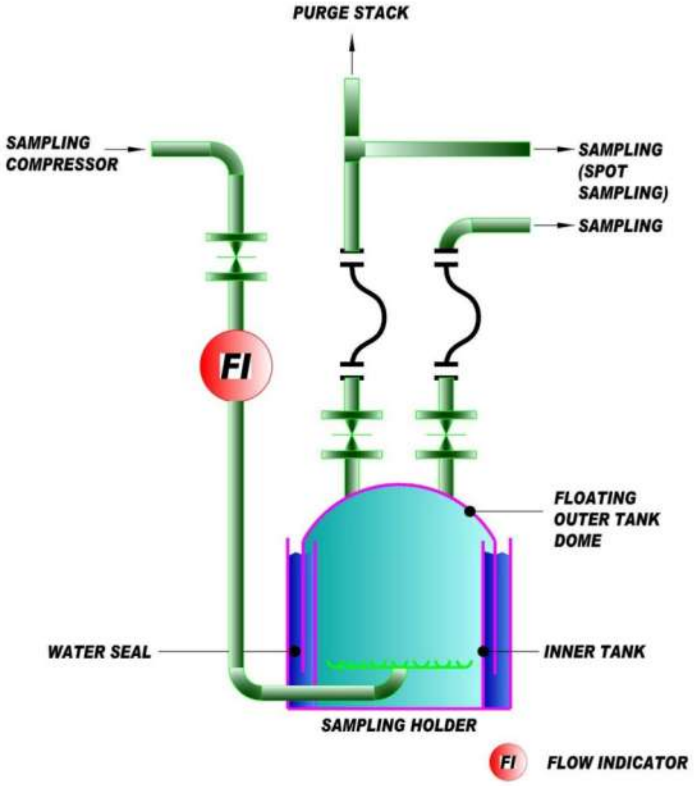
In this case, a preferably stainless steel pipe with a small diameter directly connects the outlet of the vaporizer to a manifold at the inlet of gas analyzers.
A set of fittings, regulators, valves, flow meters, etc are necessary to maintain a constant flow and pressure. A gas compressor may be required in order to make up for the pressure drop in the gas line.

6.6.3. Examples

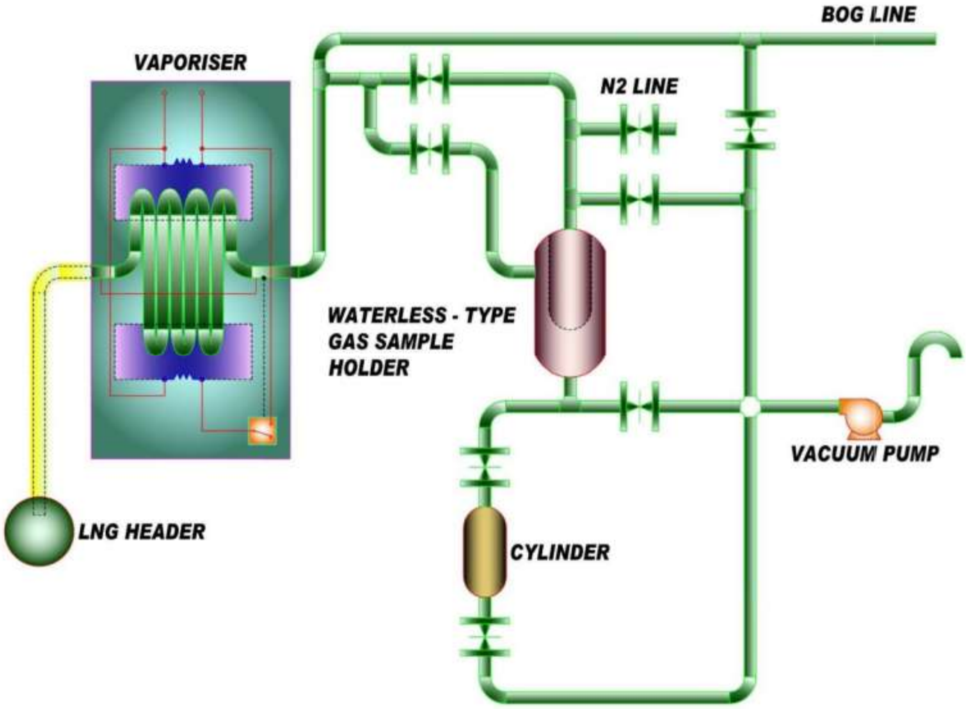
Examples of general arrangements of sampling devices can be found in Appendix 6.

FIGURE 11: EXAMPLES OF GAS SAMPLE CONTAINERS AND SYSTEMS – SEE REFERENCE [14]

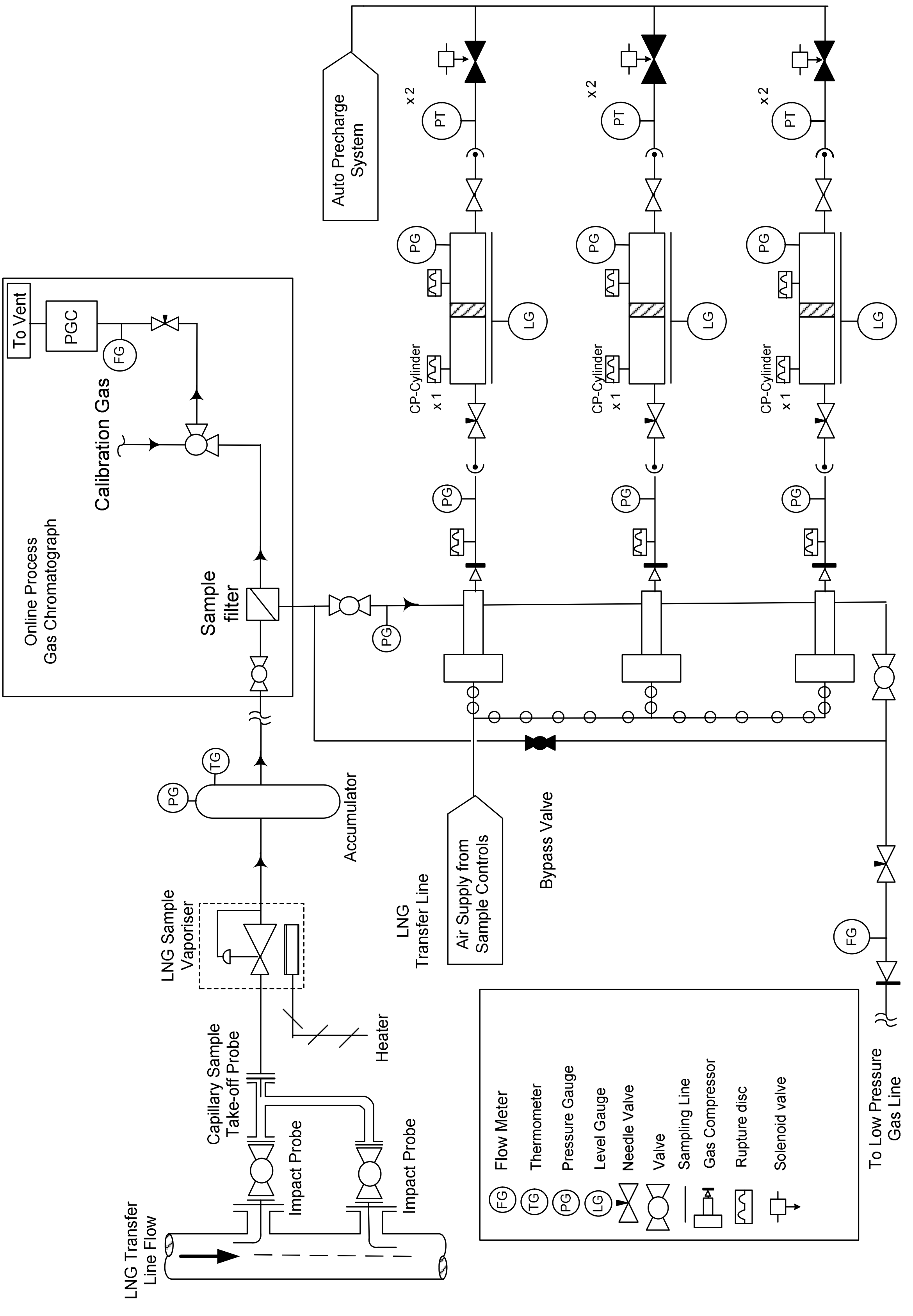
a) Water-seal type gas sample holder



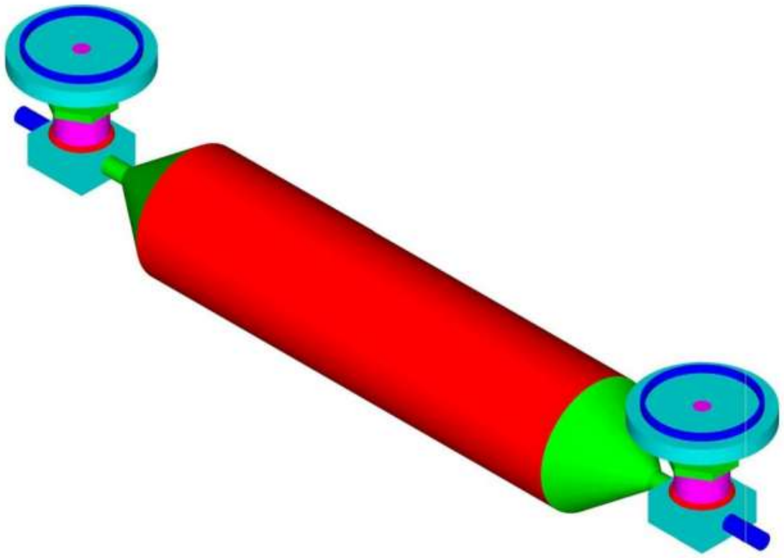
b) Waterless-type gas sample holder



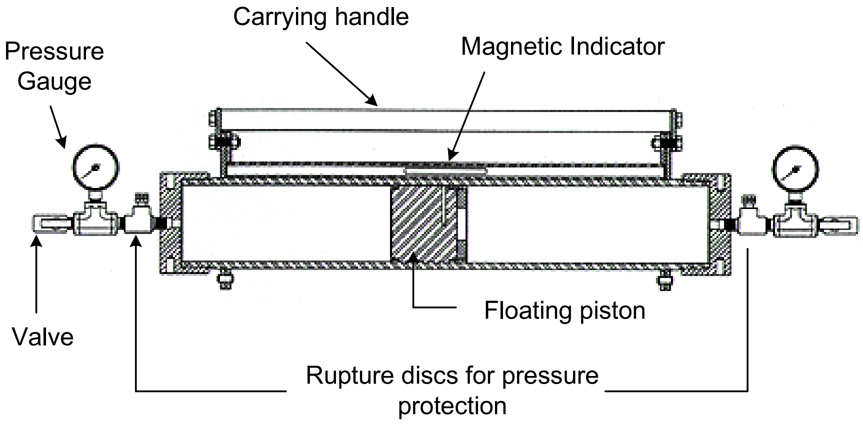
c) Intermittent sampling system



d) Metal gas sample container



e) Constant pressure floating piston sample container



6.7. PERFORMANCE OF THE DEVICES

The following remarks can be made about the design of such sampling devices and the choice of the elements which constitute them:

- to prevent or to limit possible contamination or adsorption of the heavy components (C_{5+}) stainless steel is the preferred material for all parts in contact with LNG/NG flowing between the sampling point and the analyzer, since it is less reactive than other materials. It is also recommended that lines, bottles, valves, etc. between the vaporizing device and the analyzer are kept at a constant temperature. During the filling of the gasholder or during the transfer to the analyzer/containers, the gas flow should be regulated to limit outside temperature and gas velocity effects on the adsorption/desorption phenomenon,
- low temperature LNG vaporizers (atmospheric or water at ambient temperature for instance) are not recommended because they are susceptible to fractionation,
- it is important to ensure that the sampling and vaporizing parameters remain as constant as possible during the whole sampling period, mainly LNG or gas flow rate, LNG pressure, and temperature of vaporization.

As the sampling devices have not gone through the same tests, it is difficult to compare their operating performances. Examples of calculation of operating performances of continuous and discontinuous sampling devices are given in European Standard EN12838.

6.8. SAMPLING PROCEDURE

6.8.1. Sampling period

It is recommended that the LNG be sampled when the LNG transfer flow rate is sufficiently stabilized. So it is necessary to exclude the initial period, corresponding to the starting of transfer pumps and increase of LNG flow rate, until the main pipe is completely full of LNG and until biphasic or overheated LNG contained at the beginning of the operation has been eliminated, and until the full flow rate is established. It is also necessary to exclude the final period when LNG flow rate begins to decrease before stopping completely.

When significant changes in pressure or flow rate occur in the transfer line, it is necessary to suspend sampling temporarily. Sampling can only be conducted during stable unloading/loading flow rate.

6.8.2. Sampling frequency

As far as filling of a gas holder is concerned, sampling is continuous during the sampling period, at a fixed flow rate; spot samples can be collected in addition, in order to control LNG quality and composition and to monitor the transfer operation, but the corresponding analyses are preferably not used for energy calculation.

When regasified LNG is sent directly to an online analyzer, the gas sample analysis frequency depends on the available analyzer (see Section 7.4), but typically every 5 to 10 minutes a sample is analyzed by the on-line GC. Generally these on-line GC's never stop sampling. It is important to mention that for custody transfer only the samples taken during stable (un)loading operations must be taken into account.

6.8.3. Purging

It is recommended that purging of sample conditioning equipment (line, containers, etc.) is carried out:

- ***before starting sampling:***
  - introduction of LNG, vaporization and circulation of regasified LNG in the vaporizer and pipework,
  - subsequent discharge of the purge gas either to atmosphere (small gas flow rate) or to the boil-off gas handling system of the plant,
- ***before filling the gas sample containers:***
  - connection of the container(s),
  - successively filling and emptying each container (3 times or more) before any gas sample is collected,
  - isolation and removal of the container(s).

It is advised to keep the sampling system in service between operations, so that the equipment is continuously purged and ready for a new sampling with the same operating parameters.

6.8.4. Sampling parameters

It is important that the operating parameters of the sampling device (pressure, temperatures, flow rates) are kept as constant as possible throughout the sampling period, in order to obtain a smooth operation which enables representative and repeatable sampling.

6.8.5. Utilisation of gas sample containers

Gas samples collected in containers are:

- on the one hand, directly analyzed in order to determine the average composition of LNG transferred,
- on the other hand, possibly given to the other party concerned with the transfer (purchaser or seller according to the type of LNG purchase contract,) or even kept for further investigations, in case of dispute for instance, during a period defined in the contract which may be up to several weeks.

When the sampling device includes a line whereby the regasified LNG is directly piped to the gas chromatograph, an additional system may be designed to collect spot samples (gas sample container filling station) which are then only used for control, these samples being taken on a diversion pipe at the outlet of the vaporizer with the sampling parameters being adjusted accordingly.

6.9. SPOT SAMPLING DEVICE

An appropriate quantity of LNG is injected in a properly purged chamber previously cooled down by LNG circulation. The chamber is thus partially filled with LNG, and then isolated. The LNG sample is then brought to ambient temperature and vaporizes. Thus the regasified LNG fills the whole volume of the chamber which is designed to withstand the corresponding pressure increase. Gas samples are then withdrawn from the chamber via pressure reducing valves to fill gas sampling containers.

7. GAS ANALYSIS

Sampled regasified LNG is analyzed by gas chromatography in order to determine its composition. The reason for this is to be able to calculate the physical properties needed to calculate the energy content. A direct energy content measurement by e.g. calorimeter would be less precise and would also not give the useful compositional information to calculate other properties such as density or Wobbe index.

The arithmetic average of the on-line GC analyses or the average composition of the gas chromatographic analyses of the offline retained samples shall determine the molar composition of the LNG. For the purpose of determining the molar composition, all hydrocarbon components heavier than pentane can be included in the normal pentanes fraction (C5+). Alternatively, components heavier than normal hexanes can be included in the normal hexanes fraction (C6+). The not-yet-normalized (raw) total must be between 99 and 101 mol %.

Also gas chromatography can be used to determine some impurities like sulphur components at low (ppm) levels. A different set up is often required than for the main components (see Section 7.7).

Other trace impurities, like mercury, require a different analytical technique. With most impurities sampling is critical and special precautions and sampling materials are required (see Section 7.7).

All classical techniques used to determine the composition of gas mixtures can be directly applied in the case of regasified LNG.

Many methods exist in the open literature that help technicians to analyze regasified LNG, for example in international standards series, like ISO (e.g. ISO 6974), national institutes like the Energy Institute (IP 337) or methods from institutes like ASTM (ASTM D 1945) or GPA (e.g. GPA 2261).

NOTE: it is important that, the LNG sample to be analyzed has been vaporized and conditioned correctly to be sure that the sample is truly representative of the LNG (un)loaded and thus the result of the analysis is as well (see Section 6).

7.1. TYPE OF GAS CHROMATOGRAPH

Among the various arrangements that can be found, the following are given as examples:

- a chromatograph with 2 or 3 columns to separate selectively the components, for instance: one column for N_2, C1 to C5 and one column for C6+; or one column for N_2, C1, C2 and CO_2 and one column for C3, C4 and C5. These arrangements were developed in the 1980’s and are described in the ISO, ASTM, GPA and IP methods,
- alternatively, any modern chromatographic equipment that meets the precision statements for all components to be measured in the ISO, ASTM, GPA or IP methods. A typical refinery gas analyzer will fulfil these requirements

7.2. CALIBRATION

The application of gas chromatography in natural gas is a technique that requires calibration.

There are two possibilities:

- Type 1 analysis: first determining response functions by means of a multi-point calibration using several calibration standards, followed by regression analysis. These response functions are then used to calculate component mole fractions. Type 1 analyses do not involve non-linearity errors.
- Type 2 analysis: assumes a linear response function, and subsequent sample analysis is carried out against routine calibrations using a single calibration standard. Because the assumed response function can differ from the true one, type 2 analyses can have non-linearity errors, which shall be evaluated by means of a multi-point performance evaluation carried out in accordance with ISO 10723.

The analyzer system must be calibrated or validated prior and after each loading or unloading operation. If this calibration/validation fails, a recalibration is required.

7.2.1. Calibration gas/working standard

Calibration is carried out with:

- Certified reference gas mixtures (CRMs), i.e: a reference gas mixture, characterized by a metrological valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability.
- Working measurement standard (WMS),i.e: a measurement standard that is used routinely to calibrate or verify measuring systems.

The preparation and certification of the CRM and WMS may be performed according to standards such as respectively ISO 6142 and ISO 6143.

The preferred gas mixture used as a calibration gas must include within close percentages all the components found in the regasified LNG to be analyzed. It is important that all components in the calibration gas are certified and that this is reported on the certificate, e.g. that methane content is not reported as “balance”.

However, there are also other possibilities:

- Gas mixtures could be used that do not contain all the components, but which allow the analysis of the components that are not present in the WMS by using one of the elements in it as a reference. This should however not be the case for nitrogen and C1 to C3.
- If different LNG qualities are to be analysed and only 1 WMS is available, this can only be done after the non-linearity errors have been established in accordance with ISO 10723.

7.3. ENVIRONMENT FOR A GAS CHROMATOGRAPHIC SYSTEM

The practical requirements for the installation of such a system are the same as those required for any high-accuracy analysis device and mainly involve:

- installation in a closed and temperate (not necessarily air-conditioned) housing, sheltered from the sun, heating sources or draughts. appropriate and constant temperature of calibration gases and sample (injected mass/constant volume),

- permanent and secured electrical supply, without interferences,
- shrouding and earth connections of the electrical connections between the chromatograph and the data system.

7.4. ANALYSIS OF REGASIFIED LNG AND RETAINED SAMPLES

During a normal LNG transfer operation (for instance, transfer duration of 12 hours, sampling period duration of 8 hours), the following analysis procedures can be carried out:

- in the case of direct connection between vaporizer and chromatograph: the analyses can be made successively during the whole sampling period, with a frequency equal to the duration of each analysis by the chromatographic system,
  Example: with one analysis every 20 minutes, 24 analyses are available during the sampling period. For new generation chromatographs, the duration of each analysis is reduced to 5 minutes resulting in 96 analyses,
- in case of periodic filling of sampling containers: one or more (often two) analyses can be carried out successively on each gas sampling container, with a comparison of results, and possible additional analysis or new filling of sampling containers for important threshold component concentrations. This is followed by calculation of the arithmetic average of the percentages of the components determined by the analyses considered for the determination of the average composition of the sample.
  Example: two analyses on each container filled every hour and calculation of the average, so 8 average analyses during the sampling period,
- in the case of filling of a gas holder (ISO 8943): at the end of the sampling period, three containers are filled, one for each of the seller and buyer and one kept for further investigations (e.g. an independent third party, in case of a dispute). One or more (generally two) analyses can then be carried out on the same sample and retained, if there is no significant threshold component concentration.

In any case, a data set is obtained from the regasified LNG analysis. These data have to be subjected to a statistical process to eliminate outliers, bad analyses, etc. With the remaining data an averaging and normalization treatment is normally done to get the best composition (truly representative) of the LNG volume (un)loaded (see Section 8).

From that composition the main LNG properties may be derived.

7.5. UNCERTAINTY OF GAS ANALYSIS

The uncertainty of the gas analysis should be calculated according to ISO 6974-2. Details on the uncertainty calculation can be found in Section 15.

7.6. RAMAN SPECTROSCOPY

At the time of publication of this fourth edition, a different metrology device for analysing LNG composition with direct analysis in the LNG transfer line(s) is undergoing some pilot testing.

Raman spectroscopy (see also Appendix 7) is an analytical technique that uses monochromatic light to excite and identify the vibrational modes of molecules. Each mode of each molecule generates a shift in the frequency of the scattered light. By analyzing the frequency and intensity of the scattered light, the sample's composition may be determined. The scattering interaction is so short-lived that the measurement is independent of the flow rate of the sample. The technique is viable for all phases of matter and may be effectively used on mixed phase samples. Since the intensity of scattered light is dependent on number of molecules that participate, the best results are achieved with solids, liquids and high pressure gases.

For LNG, Raman spectroscopy is accomplished through the use of an optical probe that is inserted into a product stream. The probe is typically of stainless steel construction with a small sapphire window at the tip to allow the incident laser light and scattered light to pass to the analyzer. The probe must be designed to operate at cryogenic temperatures with no loss of function to the enclosed optics. The light is passed to and from the probe through fiber optic cables in a suitably rugged cable assembly. The most basic Raman analyzer consists of a laser, spectrograph and a processor to operate them. The laser must be sufficiently stable to allow the shift in light to be consistently measured and be powerful enough to deliver close to the maximum allowable optical power to the probe tip. The spectrograph must also be capable of measuring the frequency and intensity of light to great precision. Since Raman scattering is a non-contact, non-destructive technique, calibration may be accomplished without need for custom gas or liquid samples. An instrument is calibrated by characterizing the wavelength and intensity of the laser and the sensitivity of the spectrograph. This can be accomplished with stable physical references such as neon gas or diamond crystals.

The potential of Raman scattering as an analytical technique for LNG is in its ability to measure a liquid directly without a phase change to a gas. Raman is not well suited for trace analysis of components such as sulphur.

Pilot field testing on different locations is still ongoing in view of further validation and eventual acceptance in the LNG industry.

7.7. IMPURITIES

7.7.1. General

Possible contamination of LNG is a concern because it may have safety and reliability consequences in relation to:

- LNG transfer systems,
- the sampling system and analytical instruments,
- systems and equipment in which the LNG is to be processed,
- systems and equipment exposed to vaporised LNG.

This information given here is just to raise awareness of this issue. It is realised that some contaminants and/or impurities will often be present at some (expected) level and the risk of particular consequences may depend on the level. It should be noted however that some contaminants/impurities may be cumulative.

Corrective and proactive measures may differ from site to site. The source of contamination may be at the location where the LNG is produced, in the transport carrier or possibly in the receiving system in which the LNG is processed and vaporised.

Examples of contaminants and their potential impact include:

- water: when exposed to LNG, water or water vapour turns into a solid (ice) which can block sampling systems, valves and instrument taps as well as damage equipment,
- particulates: metal shavings, welding debris, insulation, sand, wood and cloth are typical examples of particulate material. If inert, the most common problem with particulates would be blockages and damage to equipment,
- sulphur: a sampling point that utilizes copper or copper alloys may be damaged by contamination with sulphur and/or the measurement of trace sulphur compounds may be impaired by their chemical reaction with copper,
- mercury: traces of mercury may damage aluminium components by chemical reaction with the aluminium. A release of gas due to a resultant failure of the aluminium is an example of a possible safety consequence,
- other hydrocarbons: a sampling or piping system that contains, for example, traces of LPG, may result in erroneous analysis, or otherwise in “LNG out of specification”. Moreover, due to the limited solubility of butanes and higher paraffins in LNG, too high concentrations of these may also solidify and clog sampling systems. Lubricating oil and seal oil contaminants if present will be in the form of hard solids.
- Inert gases: nitrogen and air may be present in both sampling systems and piping systems from, perhaps, inadequate or poor purging operations. Moreover the presence of oxygen from the air may present a safety hazard,
- CO_2 exposed to LNG, turns into a solid similarly to water (ice) and may block sampling systems and damage equipment. Traditionally, as measured by Davis et al (1962), the solubility of carbon dioxide in the liquid and vapour phase has been 340ppm and 85ppm respectively at 111.5K and 1 bar. Recent theoretical research by Shen & Lin et al (2011-2012)[15][16] and experimental research by Gao et al (2012)[17] into CO_2 solubility in liquid CH_4/N_2 mixtures at cryogenic temperatures have identified that at any stage of the liquefaction process it is estimated that only slightly more than 100ppm of carbon dioxide could be present.

In establishing the major constituents of the LNG (for GHV determination), the danger potentially exists to ignore (trace) contaminants and/or impurities because they are normally not present at levels that exceed tolerance. The consequence may be damage to equipment, may lead to safety problems and possibly result in customer rejection of the LNG.

7.7.2. Specifications and measurement of trace impurities in LNG

Trace impurities in regasified LNG which are often specified in LNG contracts are carbon dioxide, sulphur components (hydrogen sulphide, carbonyl sulphide and mercaptans) and mercury. The trace impurities are normally in the range 0-1 mg/m^3(n) or, in case of mercury as low as 5 ng/m^3(n). Sampling cannot be done in normal cylinders for these trace impurities since they are chemically reactive and will be absorbed by the wall of the sample cylinder.

The determination of trace impurities requires a special approach. This can hardly be underestimated; set-up, operation and maintenance are an area for specialists. All aspects are critical: sampling, calibration and analysis. Validation and verification of results is strongly advised before using the results of the analyses for commercial purposes.

7.7.2.1 Carbon dioxide

The specification limit for carbon dioxide is often around 0.01 mol% (100 ppm). The carbon dioxide content is normally determined by gas chromatographic (GC) analysis which is capable of analyzing down to this limit or even lower.

7.7.2.2 Sulphur

Sulphur impurities are normally specified at the 0-25 mg/m^3(n) level.

Sulphur can be specified as total sulphur and/or as specific sulphur containing components: hydrogen sulphide (H_2S), carbonyl sulphide (COS) and mercaptans (RSH, where R is an alkyl group; e.g. methylmercaptan, CH_3SH or ethylmercaptan, C_2H_5SH).

Sampling for trace sulphur components is not so easy; special precautions are needed in order to avoid adsorption of sulphur components to the wall of the sampling system devices. Sampling in containers is preferably made according to the standard method described in ISO 10715. The interior face of the sample cylinders must be made out of a material which doesn't react with sulphur components. Even then, the sample cannot be kept for more than 8 days.

The commercially available materials "silicosteel" or “sulfinert coated steel” are suitable for this application but are very expensive.

7.7.2.2.1 Total sulphur

Total sulphur can be determined by combustion techniques, where all sulphur is converted into SO_2 which is trapped and quantified. Combustion techniques are often specified in LNG contracts and are cost effective but are not the safest to apply. Many accidents have occurred due to the rather violent combustion of gas in an oxygen/hydrogen flame.

Newer instrumental techniques like microcoulometry (ASTM D 3120), pyrolyses/chemoluminescence, or hydrogenolysis/ rateometric colorimetry (ASTM D 4045), GC/chemoluminescence (ASTM D5504) or GC/AES (ASTM D5623) are preferred.

7.7.2.2.2 Sulphur components

In order to determine the sulphur components separately in a gas, these components must be separated first. A gas chromatograph can be used for this in combination with a sulphur specific detector. The commonly used detectors (TCD - not sensitive enough for trace levels and FID - no signal at all) are not suitable. Several sulphur specific detectors are available, and are described in ISO 19739 (Determination of sulphur compound by GC). Equipment for these measurements is expensive and requires specialist skills. On line measurement is, in principle, also possible.

In principle the total sulphur can also be calculated from the components present, under the assumption that all sulphur components are detected and measured by the GC (which is normally the case, of course).

7.7.2.3 Mercury

Mercury can be determined by ISO 6978. For low levels of mercury the procedure is described in part 2: Sampling of mercury by amalgamation on gold/platinum alloy. This method is described in the range 10-100,000 ng/m^3(n) (sampling at atmospheric conditions). Mercury is normally in the form of its metal or light organic mercury components (e.g. methyl mercury). These forms are trapped effectively by amalgamation.

Mercury sampling is very critical because of the adsorption properties of mercury. Sampling lines should be as short as possible (see also ISO 10715 for materials, preferably less than a metre in length), preferably heated (80°C) especially if the gas pressure is high (above some 20 barg) to prevent possible condensation of hydrocarbons and should be flushed for a very long time (preferably even continuously at a low rate, e.g. 2 l/min).

Commercial equipment is available on the market for mercury determination but doesn't fit strictly with the recommendations of ISO 6978 which has been developed mainly for high pressure gas measurements. However, for mercury levels in LNG, commercial equipment is efficient if precautions are taken.

As with sulphur impurities, gaseous sampling for mercury in a cylinder is difficult. It is not reliable for mercury at low levels which will be adsorbed by the cylinder wall in a very short period of time causing erroneous results.

8. DATA PROCESSING & TREATMENT

8.1. GENERAL

The LNG sampling and vaporization equipment is key to Custody Transfer measurements as far as the determination of LNG quality is concerned. The aim of this equipment is to take representative LNG samples from the LNG transfer line and then to turn the liquid phase of the sample flow into the gas phase while avoiding any fractionation and selective vaporization.

Then the regasified sample flow is carried through a suitable small diameter tubing to a gas chromatograph for continued gas analysis. Typically an on-line GC is used for this purpose as described in ISO 8943.

Provided that the whole system works properly and is correctly calibrated, the gas analysis provided by the gas chromatograph and its integrator provides the molar composition of the LNG and so reflects the transferred LNG quality. In this way, and based on this molar composition, relevant LNG properties such as gross calorific value and density can be calculated from the composition.

Modern sampling and vaporization units are complemented with auxiliary devices such as pressure transmitters, temperature devices, flow meters, etc for control purposes.

In general, all signals coming from the auxiliary devices, gas chromatograph, etc. are transmitted to a distributed control system (DCS) for control and monitoring. That means that a lot of information is available for subsequent processing and treatment.

During Custody Transfer process a set of LNG compositions provided by GC is available. Since one unique LNG composition is necessary for calculating LNG relevant properties involved in the determination of the energy transferred, procedures and guidelines have to be stated and defined to deal with the available information.

8.2. DATA HANDLING: QUALITY

The molar LNG composition provided by the gas chromatograph is used to derive LNG properties. Normally density and gross calorific value are calculated by correlations and procedures from an average LNG molar composition (see Sections 9 and 10). If suitable routines are included in the gas chromatograph software it may be used to calculate these properties directly using temperature as an additional parameter.

The set of LNG compositions provided by the gas chromatograph(s) during the Custody Transfer process must be managed to produce a representative composition for the whole LNG (un)loading operation.

That is performed in two steps: processing and treatment.

8.2.1. Data processing

The aim of this step is to eliminate those LNG compositions which were produced by analyses in a period of time during which some operating parameters were outside preset limits.

For instance, when:

- the sampling rate is lower than a preset value of regasified LNG flow (e.g. 1.0 m^3(n)/h),
- the pressure at the sampling point is lower than a preset value, e.g. 2 bar (gauge),
- ship's LNG cargo discharge pumping rate is lower than a preset value, e.g. 70% of nominal rate,
- other criteria particular to the analyses.

After performing this data processing step, a subset of acceptable LNG compositions is ready for data treatment.

8.2.2. Data treatment

The aim of the data treatment is to obtain, from a statistical point of view, a robust and consistent result that best reflects the quality of the whole transferred LNG.
This step consists of:

- performing a statistical test for each analysis and each LNG component in order to determine the presence of outliers,
- evaluating the elimination or not of the detected outliers (the whole analysis must be eliminated),
- calculating the average composition from the analyses not being rejected,
- normalizing the final LNG composition.

There are different approaches to determine the presence of individual values in a set of data that may be inconsistent and may change the final result: graphical consistency technique and numerical outlier tests. These techniques are explained in ISO 5725-2 standard. One of the numerical tests recommended in this standard for dealing with outliers is the Grubbs' test. Appendix 8 shows the procedure to apply this test as well as a numerical example.

This data treatment step results in a final LNG molar composition, representative for the whole LNG (un)loading operation, from which the relevant LNG properties can be calculated.

9. DENSITY

9.1. GENERAL

There are two ways of determining density:

- the first consists of measuring its average value directly in the LNG carrier's tank by means of densitometers,
- the second enables the density to be calculated on the basis of an average composition of LNG.

In-situ measurement with the help of a densitometer takes into account the LNG state of equilibrium and composition, which means that one no longer depends on product sampling and analysis. It would therefore seem to be the best method for measuring the LNG density. Unfortunately, technological progress has not reached the stage where it is possible for a reliable apparatus to be available on board a LNG carrier under normal operating conditions. This is why the second method, which enables the density to be calculated from the LNG average composition, is the one that has been selected here.

9.2. DENSITY CALCULATION METHODS

A variety of calculation methods exists [6], such as:

- state equations in their integral form,
- method of extended corresponding states,
- hard sphere model method,
- WATSON method,
- ELF-AQUITAINE method,
- graphic method of RC MILLER,
- HIZA method,
- revised KLOSEK-McKINLEY method (k1 and k2 tables in Kelvin: K),
- ISO 6578, also using the revised KLOSEK-McKINLEY method (k1, k2 tables in degrees Celsius: °C).

Validation of these density models by experimentation is ongoing (Ref [18]). In this handbook, the preferred method is the revised KLOSEK-McKINLEY method, as described in N.B.S. Technical note 1030 December 1980 [9] or in ISO 6578. It is easy to apply and only requires the LNG temperature and composition to be taken into account. The limits of the method also encompass the composition of most LNG produced. Its uncertainty is ±0.1%, when either the nitrogen or butane content does not exceed 5%. For these density calculations an electronic spreadsheet or a computer programme is often used.

Comparison between the revised KLOSEK-McKINLEY method using tables in Kelvin (NBS) and tables in degrees Celsius (ISO 6578:1991) indicates that they are very similar with a relative difference of about 10^{-4}. Tables according to NBS only mention *components up to C5 however, while tables according to ISO 6578 mention components up to C6.*

9.3. REVISED KLOSEK-Mc KINLEY METHOD

9.3.1. Limits of the method

The method can be used within the following limits on composition and temperature:

CH_4 > 60% mol
$iC_4 + nC_4$ < 4% mol
$iC_5 + nC_5$ < 2% mol
N_2 < 4% mol
T < 115 K

9.3.2. Formula

This method is based on an empirical evaluation of the molar volume of the mixture in the thermodynamic state of the LNG considered. The density of LNG is calculated as follows:

$$D_{LNG} = \frac{M_{mix}}{V_{mix}}$$

where:

D_{LNG} = density of LNG

M_{mix} = molecular weight of the mixture
= $\Sigma X_i . M_i$
M_i = molecular weight of pure component i
X_i = molar fraction of component i

V_{mix} = molar volume of the mixture expressed in l/mol
= $\Sigma X_i V_i - \left[k1 + (k2 - k1).(X_{N_2} / 0.0425)\right].X_{CH_4}$

X_i = molar fraction of component i

V_i = volume of the component i at the temperature of the LNG

k_1, k_2 = correction factors

Tables for calculation according to NBS can be found in Appendix 9. For tables according to ISO 6578, we refer to the standard itself.

9.3.3. Example of LNG density calculation

A worked out example of LNG density calculation according to this revised Klosek-McKinley method using molecular weight of individual components from ISO 6976 is given in Appendix 10.

The calculations can be made e.g. to six decimal places and the final result can be rounded off to three decimals. More information on the rounding procedures can be found in Section 15.

10. GROSS CALORIFIC VALUE

10.1. GENERAL

The gross calorific value (GCV) of gas corresponds to (definition according ISO/DIS 6976) the amount of heat that would be released by the complete combustion with oxygen of a specified quantity of gas, in such a way that the pressure *p* at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature *t* as that of the reactants, all of these products being in the gaseous state except for water, which is condensed to the liquid state at *t*.

A coherent set is generally selected from the following reference conditions:

- ***for the determination of GCV:***
  t = 0°C or 15°C or 15.56°C (60°F) or 20°C or 25°C,
- ***for the volume condition:***
  p = 1.01325 bar absolute (14.696 psia) or, sometimes, 1.01560 bar absolute (14.73 psia),
  and
  t = 0°C,15°C, 15.56°C (60°F), 20°C or 25°C

Unless mentioned otherwise the reference conditions considered in this handbook will be:

GCV and Wobbe: t = 25°C

Gas volume: p = 1.01325 bar absolute and
t = 0°C,

referred to as "normal conditions", for which the volume is indicated in m^3(n).

Remark: *within the European natural gas transmission community these reference values have been established as EASEE-Gas Common Business Practice (CBP) (cfr. Enclosure 3).*

Another common set of conditions for volume is called "standard conditions" (15ºC, 1.01325 bara) for which the volume is indicated in m^3(s). These are recommended by ISO.

In addition, the unit of energy will be kJ, which can be then converted to BTU according to the conversion factor table in Enclosure 1.

10.2. METHOD OF DETERMINATION OF THE GROSS CALORIFIC VALUE

The gross calorific value can be determined:

- by measurement with calorimeters,
- by computation on the basis of the composition of the gas and the reference data.

10.2.1. Determination with the help of calorimeters

Several types of calorimeters can be used, among them:

- manual calorimeters,
  - deflagration calorimeters
  - with auxiliary fluid circulation exchanger
- automatic calorimeters,
  - water flow calorimeters
  - air circulation calorimeters
- empirical calorimeters,
  - with indirect measurement of the heat produced
  - infra-red absorption calorimeters
  - sonic velocity calorimeters
  - optical interferometer type calorimeters
  - Rauter gas analyzers.

A detailed study of these different types of devices can be found in References [7] and [8].

These devices enable the volumetric gross calorific value to be measured but, as LNG Custody Transfer requires the mass gross calorific value of LNG, the density of LNG must also be determined.

Since the composition of LNG is necessary for the calculation of the density of LNG (see Section 9), the gross calorific value is always calculated from composition data as well. This explains why calorimeters are not used for the purpose of LNG Custody Transfer.

10.2.2. Determination of GCV by calculation

10.2.2.1 Examples of formula

a) GCV (volumetric) expressed in coherent units, e.g. in kJ/m^3(n) or in kJ/m^3(s), can be calculated, with one of the following formulae depending on whether the ideal gas or the real gas calorific values are considered:

i) Ideal gas GCV (volumetric)

$$GCV_{(vol)} = \frac{\Sigma X_i . GCV_{i(mol)}}{\Sigma X_i . MV_i}$$

or

$$GCV_{(vol)} = \Sigma X_i . GCV_{i(mol)} . \frac{p_V}{R.T_V}$$

where:

X_i = molar fraction of component i

$GCV_{i(mol)}$ = molar gross calorific value of component i, expressed in kJ/mol

$MV\, i$ = molar volume of component i, expressed in m^3(n)/mol

p_V, T_V = gas volume metering conditions

R = molar gas constant 8.3144621 J/mol/K

the physical constants GCV$_i$ (mol) and R being specified in coherent standards, e.g. all ISO, or all GPA, … .

Note *on the "exact value" of the molar gas constant R. ISO 6976 : 1995 mentioned R = 8.314 510 J/(mol.K) and referred to CODATA 1986.ISO CD 6976:2013 adopted the latest CODATA 2010 value of 8.314 462 1 J/(mol.K).*

ii) Real gas GCV (volumetric) = ideal gas GCV divided by the compressibility factor Z

$$GCV_{(vol)} = \frac{\Sigma X_i . GCV_{i(vol)}}{(\Sigma X_i . MV_i) Z}$$

where:

X_i = molar fraction of component i

$GCV_{i(vol)}$ = molar gross calorific value of component i, expressed in kJ/m^3(n) or (s)

Z = compressibility factor of the gas mixture

the values of GCV$_i$ (vol) and the method of calculation of Z being specified in coherent standards.

ISO 6976 or GPA 2172 standard give methods for calculation of Z (and respectively ISO 6976 or GPA 2145 for GCV).

b) GCV(mass) expressed in kJ/kg can be calculated by one of the following formulae:

$$GCV_{(mass)} = \frac{\Sigma X_i . M_i . GCV_{i(mass)}}{\Sigma X_i . M_i}$$

where:

X_i = molar fraction of component i

$GCV_{i(mass)}$ = mass gross calorific value of component i, expressed in kJ/kg

M_i = molecular mass of component i, expressed in g/mol

the physical constants GCV$_i$(mass) and M$_i$ being specified in coherent standards,

Note: *In Japan the above formula is preferred.*

or:

$$GCV_{(mass)} = \frac{\Sigma X_i . GCV_{i(mol)}}{\Sigma X_i . M_i}$$

where:

X_i = molar fraction of component i

$GCV_{i(mol)}$ = molar gross calorific value of component i, expressed in kJ/mol

M_i = molecular mass of component i, expressed in g/mol

the physical constants $GCV_{i(mol)}$ and M_i being specified in coherent standards.

10.2.2.2 Examples of charts of basic physical constants

One of the following standards may be used to provide tables of physical constants and methods of calculation of factors necessary to determine the gross calorific value:

ISO 6976
ASTM 3588
GPA 2145
GPA 2172
HM 21

These standards, or other publications which are used, refer to the results of works enjoying international recognition, and except for ISO 6976, most of them, at least partly, to the works published by the American Petroleum Institute (A.P.I.), in Research Project 44.

10.2.2.3 Example of calculation

A worked out example is given in Appendix 11 (Tables A11-1, A11-2).

The worked out example is based on the use of reference tables and methods of calculation specified in the ISO 6976 standard (1995 edition).

The calculations carried out, result in the mass based gross calorific value used for the determination of the energy of LNG transferred (Table A11-1, see Appendix 11), and the volume based gross calorific value used for the determination of the energy of the gas displaced (Table A11-2, see Appendix 11).

The formulae chosen here are as follows:

- For LNG:

$$GCV_{(mass)} = \frac{\Sigma X_i . GCV_{i(mol)}}{\Sigma X_i . M_i}$$

- For gas displaced

$$GCV_{(vol)} = \frac{\Sigma Y_i . GCV_{i(mol)}}{\Sigma Y_i . MV_i}$$

Note: *In Japan the above (mass-based) formula is preferred also for gas displaced.*

with X_i, $GCV_{i(mol)}$, M_i, MV_i as defined in Section 10.2.2.1 and Y_i = molar fraction of component i in gas displaced.

It should be noted that the molar composition of the displaced gas is different from the LNG composition. It is determined either by gas analysis, or calculated. Practical calculation is possible with a simple formula based on empirical K_i values for each component. K_i for each component is defined as an empirically determined ratio between the molar fraction in the gaseous state and the molar fraction in the liquid state of that particular component.

$$Y_i = K_i . X_i$$

For practical displaced gas calculations, these K_i values are usually limited to the most significant ones i.e. of the components with the lowest atmospheric boiling points: nitrogen, methane and sometimes ethane. Considering the relatively small energy content of gas displaced compared with the energy of the LNG (un)loaded (typically less than 1%), it is generally viewed that this simple calculation approach results in a sufficiently accurate overall calculation of energy transferred.

The calculations in the example show that the contribution of ethane vapour to the GCV of gas displaced is very marginal. Therefore it can be argued that for simplicity it may even be dropped in the calculation of this GCV. Nitrogen is then the only component of which the molar fraction should either be measured in the gas returned flow, or be calculated as shown in the example in Appendix 11, Table A11-2. The following typical K_i values for nitrogen, methane and ethane at near atmospheric pressure and temperatures around -160°C are:

K_{N_2} = 23 (range: 20 – 26)
K_{CH_4} = 1
$K_{C_2H_6}$ = 0.005

The K_i values for any other component are assumed to be zero.

In this way, starting from the molar composition in the liquid state determined by LNG sampling and gas analysis, the molar composition in the gaseous state can be calculated. In the event that the sum of the thus obtained fractions does not equal 100%, a linear correction of the value of each component must be carried out.

11. ANALYSIS REPORT

A standard analysis report could be as follows:

11.1. IDENTIFICATION

- Name of the ship
- Date
- (un)loading terminal and port
- Country (origin and destination)
- Beginning of loading/unloading
- End of loading/unloading
- Reference number

11.2. BASIC DATA

- Custody transfer data before and after (un)loading:
    - level measurements in each cargo tank
    - temperatures of LNG and displaced gas
    - trim, list and thermal corrections in each cargo tank
    - volume in each cargo tank
    - mean temperature of the LNG.
    - mean temperature of the displaced gas
    - summed volume of all cargo tanks before and after (un)loading
- Certificate of (un)loading:
    - total volume (un)loaded = difference between volumes before and after (un)loading
    - cargo tanks pressure (absolute and/or gauge) and corresponding mean pressure
- Port log
- Notice of readiness
- Results of continuous/discontinuous sampling (see Section 6)
- Number of (discontinuous) samples.

11.3. RESULTS

For the transferred LNG and vapour (displaced gas, etc., see Section 12):

- Net (un)loaded LNG volume (m³)
- Net (un)loaded LNG mass (tonne)
- Mean composition of LNG (mol%), including nC+
- Molecular weight of LNG(kg/kmol)
- Pseudo-molar volume (m³/kmol)
- Corrected molar volume (m³/kmol)
- (Un)loaded LNG density (kg/m^3)
- Gas density (kg/m³) at specified conditions
- Mass gross calorific value (MJ/kg)
- Volume gross calorific value (MJ/m^3(n))
- Wobbe Index (MJ/m^3(n))
- Expansion ratio (m^3(s)gas/m^3LNG)
- (Un)loaded energy quantity (GJ)
- Vapour return energy quantity (MJ)
- Any gas to engine room energy quantity (MJ)
- LNG vessel energy consumption during (un)loading (MJ)
- Net (un)loaded energy quantity (GJ or MMBTU)

12. ENERGY OF GAS DISPLACED OR CONSUMED

To complete the calculation of net energy of the LNG transferred, the figure derived from the liquid volume calculation may be adjusted for:

- The gas sent back from the ship during the loading operation or the gas transferred to the LNG carrier during the unloading operation expressed in energy terms is determined as described in Section 12.1. This may be referred to as 'buy-back' gas. This gas is not commercial natural gas nor vaporized LNG but BOG whose composition is mainly methane and some nitrogen.
- and the gas possibly consumed by the LNG carrier as fuel in the engine room or in the ship's GCU (gas combustion unit) during the operation, determined as described in Section 12.2. This gas can be either BOG similarly to the 'buy-back' gas if the ship takes its fuel gas in gaseous form directly from the vapour header, or vaporized LNG if the ship takes its fuel gas in liquid form from its cargo tanks with a small spray pump before the LNG gets regasified and injected into the engine/burner (e.g. ships with dual fuel motors).

12.1. ENERGY OF GAS DISPLACED FROM THE LNG TANKS

This quantity is determined by the following formula, whether it is received by or sent back to the ship.

$$E_{gas\ displaced} = V_{LNG} \frac{273.15}{273.15+T} \cdot \frac{p}{1.01325} \cdot GCV_{gas}$$

where:

E_{gas} = quantity of energy in gaseous form displaced during loading or unloading, expressed in MJ

V_{LNG} = volume of the LNG loaded or unloaded, expressed in m^3

p = absolute pressure in the tanks, expressed in bar

T = mean value of the temperatures of the probes not immersed in LNG, expressed in Celsius degrees.

GCV_{gas} = GCV of the gas in gaseous state contained in the ship's tanks, expressed in MJ/m^3(n) or MJ/m³(s) in accordance with ISO 6976.

As indicated in Section 2.3.3, the parameters p, T and GCV_{gas} can be either measured, estimated, or taken as constants determined by experience. Any resulting inaccuracy would only concern the energy of gas displaced which represents less than 1% (typically about 0.3%) of the quantity of energy in the LNG transferred and may therefore be negligible. In Japan it is common practice to assume the return gas to be 100% methane in the calculation of the energy of gas displaced.

For example:

T = -140°C
GCV_{gas} = 36 MJ/m^3(n)
p = 1.150 bar

and in this case, the formula can be simplified and becomes, with energy expressed in MJ:

$$E_{gas\ displaced} = 83.82 \ . \ V_{LNG}$$

12.2. ENERGY OF GAS CONSUMED AS FUEL BY THE LNG CARRIER

The LNG carrier, subject to agreement of buyer and seller, may use gas as fuel in its engine room during the loading operation (FOB cargo) or unloading operation (CIF or DES cargo), between the opening and closing CTS.

This amount of energy can be determined:

- either by the measurement of the total volume of gas V_g consumed (gas flow meter on board the LNG carrier) and the evaluation of the GCV of gas as described in Section 12.1 for LNG vessels using boil-off gas as fuel:

  $$E_{fuel\ gas} = V_g . GCV_{gas}$$

  For LNG vessels using forced vaporisation of LNG cargo, the quality of the LNG (un)loaded can be taken,
- or by a formula agreed by the seller and the buyer and based on the average gas consumption experienced for a given ship at the occasion of its first (un)loading whilst burning gas as fuel. This formula may take into account the duration of the operation, the electrical power consumption of the LNG cargo pumps and/or gas compressors (blowers) and ballasting pumps in operation in the time interval between the opening and closing custody transfer surveys (CTS) and the actual average efficiency of electrical power generators in the engine room. Considering that the amount of energy of gas consumed in the engine room is small compared with the overall uncertainty of the energy of the LNG transferred, parties may agree on a contractually assumed amount of energy of the gas consumed on board during the time interval between the opening and closing CTS's.

For an LNG carrier of 125 000 to 145 000 m³ LNG with steam boilers and a steam turbine propulsion plant, the energy of the gas consumed in the engine room between the opening and closing CTS may typically amount to some 0.05 to 0.06% of the total energy of LNG transferred.

On the other hand, for an LNG carrier of 155 000 to 175 000 m³ LNG with dual fuel diesel electric propulsion, this percentage may rather be of the order of 0.04% or even lower.

This percentage will depend on several factors:
- the ratio of BOG consumption versus total fuel consumption in the engine room,
- the energy technology on board the LNG carrier, refer the "Energy Efficiency Design Index" (EEDI),
- the power and energy management in place on board the LNG carrier, refer the "Energy Efficiency Operational Index" (EEOI),
- the time interval between the opening and closing CTS (e.g. extended if the LNG transfer rate has to be reduced for operational reasons),
- the size of the LNG carrier.

The above-mentioned typical percentages refer to standard (un)loading periods of some 12 to 14 hours. The percentage of energy of gas consumed as fuel by the LNG carrier would be higher if the duration of the LNG transfer operation is increased. But it could also be lower, for instance, when a ship is reloaded at an LNG regasification terminal and the ship's cargo transfer pumps are not running. In this case the ship's GCU (gas combustion unit) can be running as well in order to handle the boil-off gas produced, hence reducing the vapour sent back to the shore or ship being unloaded.

13. ENERGY TRANSFER DETERMINATION

The activities required for proper custody transfer during LNG (un)loading are described in the previous sections of this handbook. When the measurements and calculations have all been completed the net energy transfer can be calculated by applying the formula in Section 2.1.

Table 6 gives an example framework for a quantity certificate for the LNG terminal's and ship's records of an unloading variation.

14. ENERGY TRANSFER MEASUREMENT

All elements enabling the determination of the energy transferred have now been determined. The formula for calculating the LNG transferred (mentioned in section 2.1) can now be applied within the framework of Table 6 given as an example for:
- Quantity certificate at the LNG terminal
- Unloading / loading certificate for commercial use.

15. UNCERTAINTY OF THE ENERGY TRANSFER DETERMINATION

The evaluation and expression of uncertainty in measurement shall be in accordance with the principles established in the ISO document *Guide to the expression of uncertainty in measurement*. The following sections describe the main sources of uncertainty for each variable involved in the energy transfer determination, in order to help users to elaborate the uncertainty budgets. Note that situations with malfunctions are not considered in the calculations.

15.1. VOLUME

There are many measurements involved in the determination of the volume of an LNG carrier. The uncertainty must take into account all of them, although some uncertainty contributions are negligible. The following table shows the main sources of uncertainty in the determination of the LNG volume (see typical values in Appendix 12).

Table 2: SOURCES OF UNCERTAINTY IN VOLUME

Source of uncertainty	***Value***
Gauge tables	Calibration Certificate
Level	Note 1
Liquid temperature	Calibration Certificate
Vapour temperature	Calibration Certificate
List (if applicable)	Calibration Certificate
Trim (if applicable)	Calibration Certificate
Tank thermal expansion factor (Spherical tanks)	Bibliography

Note 1: The uncertainty of the level measurement shall be determined taking into account the following sources of uncertainty: intrinsic uncertainty of the gauge, the deviation of the mean (standard deviation), and the uncertainty of the corrections.

The volume uncertainty is strongly influenced by the uncertainty of the gauge tables, which can significantly vary from one LNG carrier to another. The uncertainty generally guaranteed by the contractor's calibrations is ±0.2 % at ambient temperature. A study carried out by the National Bureau of Standards (NBS) [8] on the calibration of the tanks of LNG carriers shows that the real uncertainty is far better, and is about ±0.05 % to ±0.1 %. Also according to this study, the systematic uncertainty due to the effect of shrinkage of the tanks when they have been cooled down should not be more than 0.07 %. Therefore, for a tank of 26 000 m^3, the maximum guaranteed uncertainty is ±52 m^3 LNG, but in practice it is around half of that taking into account the NBS study noted above.

In case the LNG carrier is not placed in a well-protected area, the uncertainty due to sagging and hogging should be included in the uncertainty calculation (only for membrane tanks).

The volume uncertainty of one tank can typically vary from 0.20 % to 0.55 % (k = 2). To determine the volume uncertainty of the whole LNG carrier, it is necessary to take into account the correlation between the parameters involved: some sources of uncertainty are highly correlated (tank calibration or measurement system) whereas others can be considered as uncorrelated (each tank has individual gauges for level, temperature and pressure). Nevertheless, it may be difficult to determine the degree of correlation (positive correlation); thus, a conservative approach is assumed and the uncertainty of one tank can be used as the uncertainty of the whole LNG carrier.

Note that in 3.01 edition the volumes of each tank were considered as uncorrelated (independent), obtaining that the uncertainty of the whole volume was less than the uncertainty of one tank. In this edition, a more conservative approach is used, avoiding an underestimation of the uncertainty.

Note for spherical tanks:
For spherical tanks, owing to their geometry, the volume uncertainty, as a result of the small inaccuracies of the level gauge, is significantly less than for prismatic membrane tanks.

15.1.1. Cargo Liquid Lines

The previous section addresses the uncertainty of volume measurement of the cargo tanks. To have a full picture, the issue of contents of the cargo liquid lines needs to be considered.

As specified in Section 3.3 and in the ISO standard ISO 6578, cargo lines should be maintained in the same condition of pressure, temperature and density (liquid or vapour) during the opening and closing Custody Transfer Surveys (CTS).

For most 'flat-deck' designs of LNG Carrier (e.g. older membrane-type and IHI-SPB), the arrangement of cargo lines on deck is such that, at completion of cargo operations, all liquid left in the liquid lines can drained by gravity back to a cargo tank.

Once the drainage is completed, custody transfer measurements can proceed as described and there is no need to consider liquid in the cargo lines.

For all spherical tank designs and for maximized membrane type designs where the manifold valves are below the crossover lines, some consideration is needed for undrainable liquid.

Significant volumes of LNG may remain in the cargo manifolds and crossovers after completion of delivery, typically well over 50 m³ LNG for the larger ocean-going LNG carriers. The fact that this volume often exceeds the total accuracy on volume measurement, underlines the importance of the ship’s cargo lines being in the same condition of density (i.e. liquid or vapour), during the opening and closing CTS. If this is the case, the normal approach is to pre-cool and completely fill the cargo lines with LNG prior to the first CTS reading on arrival. The assumption is that LNG volume in liquid lines is the same at the time of both opening and closing CTS readings, and therefore can be ignored in the calculation.

15.2. DENSITY

The following table summarizes the sources of uncertainty in LNG density calculation:

Table 3: SOURCES OF UNCERTAINTY IN DENSITY

Source of uncertainty	***Value***
Calculation method (KMK)	Bibliography
Composition	From ISO 6974
Molecular weight	Values taken from ISO/DIS 6976
Molecular volume	Bibliography
Liquid temperature	Calibration Certificate
K_1, K_2	Bibliography

As most input parameters are correlated to the composition analysis, the application of the conventional uncertainty analysis, stated in GUM, is complex. In these cases, the Monte Carlo method is a practical alternative for the evaluation of the measurement uncertainty. In case of LNG density, a Monte Carlo simulation was used for 1000 different compositions (see Appendix 12), obtaining an outcome of the simulation of 0.45%.

15.3. GROSS CALORIFIC VALUE

The uncertainty of the GCV is described in detail in ISO/DIS 6976 (see equation in Appendix 12), whose sources of uncertainty are:

Table 4: SOURCES OF UNCERTAINTY IN GCV

Source of uncertainty	***Value***
Composition	From ISO 6974
Molar mass of each component	Table from ISO/DIS 6976
GCV of each component	Table from ISO/DIS 6976

Using the equations as given by ISO/DIS 6976, typical values for the uncertainty of the mass based GCV are between 0.04 % and 0.07 % (k = 2).

15.4. SAMPLING AND VAPORIZATION

The uncertainty due to sampling and vaporization has an impact on the composition measurement and is therefore influencing both the uncertainties on the GCV and the density. The uncertainty due to sampling and vaporization is obtained from the repeatability of the analyses, which is already included in the calculation of the composition uncertainty from ISO 6974. This uncertainty can be up to 0.3% according to NBS [8] Situations where the vaporization fails and the sample is non-homogeneous are not taken into account.

15.5. GAS DISPLACED

The gas displaced represents about 0.3% of the total quantity transferred and the total uncertainty of the parameters used in the calculation is ± 1%. The uncertainty resulting from the calculation of gas displaced in the energy transferred is therefore about ±0.003% and can be considered negligible.

15.6. GAS CONSUMED IN ENGINE ROOM

The gas consumed in the LNG carrier's engine room during the time between opening and closing custody transfer surveys may typically amount to some 0.05 to 0.06 % of the total energy of LNG transferred (see 12.2) and the total uncertainty of the parameters used in the calculation is ± 1%. The uncertainty resulting from the calculation of gas consumed in the energy transferred is therefore about ±0.0006 % and can be considered negligible.

15.7. COMBINED STANDARD UNCERTAINTY AND EXPANDED UNCERTAINTY OF THE ENERGY TRANSFER DETERMINATION

The combined relative uncertainty obtained for the energy transferred can be calculated as:

$$u_E = (u_V^2 + u_\rho^2 + u_{gcv}^2)^{1/2}$$

The following table sums up the typical values of the expanded uncertainties involved in the determination of the energy uncertainty (see Appendix 12). These values can be used as reference; however, the uncertainty budgets should be determined for each (un)loading.

Source of uncertainty	***Typical Values (k = 1)***
Volume	0.10 % - 0.27 %
Density	0.23 %
GCV	0.02 % - 0.04 %
Energy	**0.25 – 0.37 %**

The combined expanded uncertainty (also sometimes called "overall uncertainty") of measurement with 95% confidence level (coverage factor k=2) of the energy transferred is 0.5 – 0.7%.

Note: if the correlation between density and GCV (both variables are obtained from the LNG composition) is taken into account (negative correlation in this case: increase of density implies decrease of GCV, and vice versa), the above figures decrease slightly.

15.8. ROUNDING OF NUMBERS AND COMMERCIAL IMPACT

According to ISO 80000-1 (Annex B) “rounding” means replacing the magnitude of a given number by another number called the “rounded number”. Two different rules (rule A and B according to ISO 80000-1) are in use for this purpose but the rule B is in generally preferable (used in computers).

- The greater in magnitude multiple is selected as the rounded number if the last digit is ≥ 5.
- The lower in magnitude multiple is selected as the rounded number if the last digit is < 5.

Examples:

- 12.24 is rounded to 12.2
- 12.25 is rounded to 12.3
- 12.26 is rounded to 12.3

When a number is given without any further information, it is generally interpreted so that the last digit is rounded. For example, the number 401 008 is assumed to represent a value between 401007.5 and 401008.4. In this case, the maximum magnitude of the error in the number 401008 is ±0.5. Rounding shall not be replaced by truncation (i.e, by simply cutting off the last digits) e.g. 401 007,9 becomes 401 007. In this case, the number 401 007 represents a value from 401 007,0 to 401 007,9 and the error is smaller than+1.

Rounding of numbers shall always be carried out in the last step because rounding in more than one stage may lead to errors. Besides, accuracy can’t change during mathematical operations. On the other hand, numerical values of parameters have an associated standard expanded uncertainty. Uncertainty has to be expressed in absolute terms with two significant figures (see ISO 80000-1 for definition of “significant digits”) ant it sets the limit of significant figures of a measure. The numerical value of the property shall be rounded to the least significant figure in the rounded value of the expanded uncertainty.

For the purposes of Custody Transfer Handbook, the unloaded or loaded energy is calculated with the following equation:

$$E = V_{LNG} \text{ x } D_{LNG} \text{ x } GCV_{LNG} - E_{\text{gas displaced}} \pm E_{\text{gas to ER}}$$

Following the rules given before, it is recommended to round off the values of the parameters to obtain an equal number of significant digits for each parameter, such as is mentioned in Table 5. In this case both the volume, the mass based GCV, the density and the energy have a similar number of significant figures (6). An example showing the commercial impact of rounding of numbers is shown in Appendix 13.

Table 5: DECIMAL PLACES FOR PARAMETERS

Parameter	Units	Decimal	Typical value
Volume (un)loaded	m^3	0	140 000
LNG density	kg/m^3	3	450.341
LNG GCV (on a mass basis)	kWh/kg	4	15.2046
Energy	MWh	0	953 685

16. SHIP-TO-SHIP LNG TRANSFER OPERATIONS

Ship-to-ship (STS) LNG transfer operations enhance the transfer of LNG from one vessel to another vessel. This can be done directly, in open water, but also indirectly by means of intermediate jetty/jetties and/or piping infrastructure.

A basic example of a ship-to-ship operation is the unloading of LNG at a reception place without receiving facility on shore. For this purpose, a FSRU (Floating Storage and Regasification Unit) is used. This vessel receives LNG from another vessel and has regasification facilities on board to regasify the received LNG and to send the natural gas to a (shore) gas pipeline.

For ship-to-ship LNG transfer operations special attention is required with regard to the detailed analysis of the following aspects: physical vessel compatibility, ship-to-ship communication and cargo management (in particular sloshing limits, boil-off management and cargo transfer rate). Ship-to-ship operations also require careful monitoring and management of the manifold connection and the mooring/fender arrangement.

The method to obtain the energy transferred in a STS operation depends on the contract between the different parties or the agreed (terminal) rules, but it is usual to apply the standard rules for the unloading of the discharging vessel into the receiving vessel.

For a ship-to-ship LNG transfer operation from a discharging vessel into a FSRU, the seller/discharging vessel is responsible to provide and maintain the custody transfer measurement systems for volume, temperature and pressure determination on board the LNG vessel and the buyer/receiving vessel is responsible to provide and maintain the custody transfer measurement systems at the FSRU, such as the gas sampling and gas analysis systems. However, some FSRU’s are not fitted with gas sampling systems to determine the quality of the received LNG. In this case there are some alternatives to be considered:

  - the best option is to calculate the estimated LNG quality received. This estimation has to take into consideration the ageing process of the LNG, the LNG quality originally loaded, the voyage duration and the data of the loading Closing Custody Transfer and the STS Opening Custody Transfer. It is common practice that the estimation is done by an independent third party as for instance the independent surveyor.
  - an alternative is to use a portable testing apparatus, vaporizer and gas chromatograph to determine the quality delivered.
  - the LNG quality originally loaded is considered as being the LNG quality received. This option does not take into account any ageing of the LNG and hence can lead to significant errors.
  - the quality of the gas measured in the shore pipeline is considered as the LNG quality received. This is also not the best option, as it is not always possible to determine if the gas in the pipeline has its origin 100% in the regasified LNG from the STS operation or whether it is a mix of different cargoes.

For ship-to-ship LNG transfer operations from a (regular) LNG vessel into another regular LNG vessel, the custody transfer measurement can be established as follows:

  - STS LNG transfer between two (regular) LNG vessels or between a large LNG vessel and a small(er) LNG vessel (split of a cargo in parcels) on sea, i.e. without connection to a shore jetty or pipeline. In this case it is recommended to have a gas sampling and analysis system on board of one of the LNG vessels. Otherwise one of the above mentioned methods might be used.
  - STS LNG transfer between two ships moored at two jetties of a land based (receiving) terminal. In this case the gas sampling system installed on the pipeline(s) of the (receiving) terminal are to be used to determine the LNG quality transferred. It is recommended to use the sampling system which is installed as close as possible to the unloading vessel in case more than one sampling system is available.

17. SMALL SHIP-TO-SHORE LNG OPERATIONS

(Un)loading of small scale carriers brings some additional considerations when compared to classical large scale ship-to-shore transfers. Special attention should be paid when performing small ship operations at a terminal designed for large scale carriers, and modified to accept small scale vessels.

- Care should be taken to ensure proper location and type of LNG sampling probes when used in reloading operations. The probe shall be located as described in section 6.2, but shall be located in a position that ensures the probe receives an LNG flow representative of the loading flow. If a single loading line is used, then the sample probe must either be located in main loading header, or the probe must be installed in the line which is in service during the operation. Similarly, the probe should be located at a suitable point in the process which allows for sufficient pressure to enable correct sampling.
- Sample probes shall be bi-directional if used in the reverse flow direction.
- Whilst large scale LNG carriers are dedicated to LNG service, small scale vessels may be certified for multi-product service, providing an increased risk of contamination to the terminal. Additional precautions may be considered to prevent contamination of the BOG, particularly when the previous cargo may differ from LNG. It may be prudent to perform a check of the cargo history, and where necessary, perform additional sampling prior to loading if there is any doubt about the previous cargoes.
- For vessels arriving without an LNG heel, please refer to the guidelines in section 2.6 for gassing-up and cooling down. In some cases, it may be prudent to perform additional manual sampling prior to connection of the vapour return line.
- The uncertainty figures provided in section 15.1 for the volume measurement are those typical for large scale LNG carriers. For small scale vessels, the individual cargo tank uncertainty, the accuracy of the level measurement, and a reduced number of cargo tanks, may all contribute to an additional overall uncertainty. These factors should be considered when determining the overall uncertainty. As the flows are generally quite small (typically 500 to 1 500 m³/h) compared to large scale LNG transfers (over 10 000 m³/h), there might be potential for future use of LNG flow meters (ultrasonic/coriolis) to determine the volume transferred, instead of using the cargo tank tables of the small scale LNG carrier, see also Appendix 1.

18. RELOADING OPERATIONS IN REGASIFICATION TERMINALS

Regasification terminals are designed to receive LNG carriers and unload their cargo. Some of them have recently been adapted to diversify their activities such as for (re)loading operations. However, the operational conditions during a reloading operation at a regasification terminal may differ from those at a liquefaction terminal.

Particularly, the temperature of the LNG to be reloaded is usually higher. For safety and efficiency reasons, carriers may require to decrease the final LNG temperature, which is generally achieved by keeping the pressure low in their cargo tanks by sending a significant amount of return gas to the receiving terminal with the ship’s blower(s). The reloaded LNG will be flashing (excessive boiling) in the ship’s cargo tanks, resulting in a difference between the final composition of the LNG reloaded in the ship and the LNG quality obtained from the sampling system of the terminal. This phenomenon is similar to the natural ageing of LNG during a ship's voyage. The difference between these two LNG compositions may introduce a significant systematic error in the estimation of the energy transferred.

This error could be avoided by calculating the LNG density and GCV from the actual LNG composition in the cargo tanks instead of the composition determined in the terminal's pipelines before the ageing. However, as LNG carriers are generally not equipped with LNG composition determination devices, an alternative to estimate the LNG composition could be the application of a mass balance to the ship, for which a proper measurement of the gas return flow and quality would be required, in addition to the devices already used in the LNG Custody Transfer Handbook.

19. LNG SALES CONTRACT CUSTODY TRANSFER CHECKLIST

The following is a tabulation of custody transfer issues to consider for inclusion in an agreement for purchase and sale of LNG.

- Definitions and Units of Measure
  - Energy units: British Thermal Unit, BTU (or metric equivalent, e.g. kJ, and their multiples, MMBTU or GJ)
  - Calorific Value: gross (or net), by volume and by mass, reference temperature for combustion,
  - Calorific Value units (BTU/kg, BTU/m^3(n), BTU/scf, MJ/kg, MJ/m^3(n), etc.)
  - Reference temperature and pressure for volume (normal or standard conditions)
  - Volume units (normal or standard cubic metre or standard cubic foot)
  - Temperature (degrees Celsius)
  - Pressure (Pa, bar or psi)
  - Mass (kg)
  - Density (kg/m³)
  - Wobbe index
  - Mole fraction
  - Significant figures

- LNG Quality Specifications
  - Upper and Lower Limits for:
    - Gross Calorific Value (or Net)
    - Wobbe Index
  - Density at temperature
  - Composition limits
    - methane
    - ethane
    - propane
    - i-butane
    - n-butane
    - i-pentane
    - n-pentane
    - hexane plus
    - hydrogen sulphide
    - carbonyl sulphide
    - mercaptan sulphur
    - total sulphur
    - oxygen
    - carbon dioxide
    - nitrogen
  - Contaminants
    - particulates
    - water
    - mercury
    - oil

- Transferred LNG Energy Quantity Determination
  - Ship provisions
  - Shore provisions
  - Calculation methods (Revised Klosek-McKinley, ISO, HIZA, etc.)

- Vapour Displaced, optional: Gas to Engine Room
  - Consideration in Quantity Determination
  - Impact of delay of LNG transfer

- Measurement
  - Ship measurement devices
  - Shore measurement devices
  - Measurement device accuracy, repeatability (certificates)
  - Calibration of measurement devices, analyzer, tank gauging
    - Standard, method
    - Frequency of calibration
  - Independent surveyor
  - Standards and guides (GIIGNL Custody Transfer Handbook, ISO, etc.)
  - Condition of ship, shore at gauging prior to and at completion of LNG transfer (e.g. ship's trim and list)
  - Level measurement device specification, identify primary and secondary level gauge
    - Verification of consistency in comparison
    - Tolerance of difference
  - Pressure measurement
    - Measurement device specification
    - Each ship tank
  - Witnesses to measurement (opening and closing custody transfer surveys)
  - Method of recording
    - Number of gauge readings, time interval
    - Manual, electronic
  - LNG Sampling
    - Location
    - Timing, frequency/interval
    - Flow-proportional
    - Basis for rejection (accuracy)
    - Method of sample vaporization
    - Method of analysis (gas chromatograph)
    - Location of analyzer (i.e. laboratory)
    - Reserve samples – quantity, retention period

- Buyer/Seller obligations and rights
  - Ship tank gauging – level, temperature, pressure, list, trim, correction (tables) for secondary level gauge
  - Barometric pressure gauging
  - LNG sample collection
  - Boil-off sample collection
  - Sample analysis
  - Certification - tank gauge tables, instrument calibration

  - Witness calibration, measurement
  - Independent surveyor
  - Costs
  - Notification
  - Records preservation

- Actions Upon Deviation
  - Failure of instruments
  - Uncertainty in measurements, readings, calculations
  - Off-specification

TABLE 6: EXAMPLE CERTIFICATE FRAMEWORK

$$E = (V_{LNG} \, . \, D_{LNG} \, . \, GCV_{LNG}) - E_{gas\ displaced} \pm E_{gas\ to\ Engine\ Room}$$

(6) (1) (2) (3) (4) (5)

ENERGY TRANSFER DETERMINATION

QUANTITY	UNITS
Liquid volume before loading/unloading	m^3
Liquid volume after loading/unloading	m^3
Liquid volume transferred (1)	m^3
Density (2)	kg/m^3
Mass of the liquid transferred	kg
Gross calorific (heating) value (3)	MMBTU/kg GJ/kg MWh/kg
Energy of LNG transferred	MMBTU GJ MWh
Energy of gas displaced (optional, see Section 12.1) (4)	MMBTU GJ MWh in kg equivalent LNG in m^3 liquid equivalent LNG
Energy of gas consumed as fuel on board ship during (un)loading operation (optional, see Section 12.2) (5)	MMBTU GJ MWh in kg equivalent LNG in m^3 liquid equivalent LNG
Net energy transferred (6)	MMBTU GJ MWh

The quantities expressed in kg equivalent LNG or in m^3 equivalent LNG are used for customs purposes only.
(Please refer to flowchart, Section 2.2.5)

ENCLOSURE 1: CONVERSION FACTOR TABLE FOR ENERGY UNITS (1), (2)

	MM British Thermal Units 10^6 BTU (MMBTU)	**Gigajoule 10^9 joules (GJ)**	**Kilowatt-hour (kWh)**	**Gigacalorie 10^9 calories (Gcal)**
MMBTU	1	1.055056	293.071	0.251996
GJ	0.947817	1	277.778	0.238846
kWh	0.00341214	0.0036	1	0.000859845
Gcal	3.96832	4.1868	1163.00	1

(1) at the same calorific reference temperature; N.B.: all temperatures in accordance with IPTS-68 (International Practical Temperature Scale 1968, cfr. http://www.bipm.org/en/measurement-units/history-si/temperature-scales/), unless all parties would agree to use ITS-90 as the reference temperature scale. Please note that in the practical temperature range for LNG custody transfer, the differences between IPTS-68 and ITS-90 are of the order of 0.01 K or less, and hence nearly insignificant and irrelevant, especially when considering the inaccuracy of temperature measurement and the overall uncertainty (cfr. Section 15).

(2) this table is for information only, please refer to ISO 1000 for full details

ENCLOSURE 2: LNG AND NATURAL GAS CUSTODY TRANSFER METHODS

ISO standard methods, being the highest level of international methods, are to be recommended. Equivalent alternatives, as indicated, from other institutes, like GPA, IP or ASTM can also be used, and may be agreed between all parties involved. It is however recommended to consistently and coherently use either ISO or GPA references or other consistent contractual requirements. In other words, a mix of ISO, GPA and/or other reference documents should be avoided.

These methods are regularly updated and readers are strongly advised to check that they are in possession of the latest issues.

METHOD	TITLE (alternative method)
General methods	
ISO 4259	Petroleum Products - Determination and application of precision data in relation to methods of test
ISO 5725-1	Accuracy (trueness and precision) of measurement methods and results - Part 1: General principles and definitions
ISO 5725-2	Accuracy (trueness and precision) of measurement methods and results. Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.
ISO 7504	Gas analysis – Vocabulary
ISO 13686	Natural gas – Quality designation
ISO 14111	Natural gas – Guidelines to traceability in analyses
ISO 14532	Natural gas – Vocabulary
EN 1160	Installations and equipment for Liquefied Natural Gas – General characteristics of Liquefied Natural Gas
EN 437	Test Gases – Test Pressures – Appliance Categories
ISO 28460	Petroleum and Natural Gas Industries – Installation and equipment for Liquefied Natural Gas – Ship to shore interface and port operations.
ISO/IEC Guide 98-3	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)
ISO/IEC Guide 98-3:2008/Suppl 1	Propagation of distributions using a Monte Carlo method
Sampling LNG/natural gas	
ISO 8943	Refrigerated light hydrocarbons fluids – Sampling of liquefied natural gas – Continuous and intermittent methods
ISO 10715	Natural gas – Sampling guidelines
EN 12838	Installations and equipment for liquefied natural gas – Suitability testing of LNG sampling systems
Calibration Gas Chromatographic Equipment	
ISO 6141	Gas analysis – Requirements for certificates for calibration gases and gas mixtures
ISO 6142	Gas analysis – Preparation of calibration gas mixtures - Gravimetric method
ISO 6143	Gas analysis – Comparison methods for determining and checking the composition of calibration gas mixtures
ISO 16664	Gas analysis – handling of calibration gases and gas mixtures-Guidelines
ISO/TR 24094	Analyses of Natural Gas – validation methods for gaseous reference material
Analysis Composition/heating value	
ISO 6974-1	Natural gas – Determination of composition and associated uncertainty by gas chromatography – Part 1: General guidelines and calculation of composition

METHOD	TITLE (alternative method)
ISO 6974-2	Natural gas – Determination of composition and associated uncertainty by gas chromatography – Part 2: Uncertainty calculations
ISO 6974-3	Natural gas – Determination of composition with defined uncertainty by gas chromatography – Part 3: Determination of Hydrogen, Helium, Oxygen, Nitrogen, Carbon dioxide and Hydrocarbons up to C_8 using two packed columns
ISO 6974-4	Natural gas – Determination of composition with defined uncertainty by gas chromatography – Part 4: Determination of Nitrogen, Carbon dioxide and C_1 to C_5 and C_{6+} Hydrocarbons for a laboratory and on-line measuring system using two columns
ISO 6974-5	Natural gas – Determination of composition and associated uncertainty by gas chromatography – Part 5: Isothermal method for Nitrogen, Carbon dioxide and C_1 to C_5 hydrocarbons and C_{6+} Hydrocarbons
ISO 6974-6	Natural gas – Determination of composition with defined uncertainty by gas chromatography – Part 6: Determination of Hydrogen, Helium, Oxygen, Nitrogen, Carbon dioxide, and C_1 to C_8 hydrocarbons using three capillary columns.
ISO 6975	Natural gas – Extended analysis – Gas chromatographic method (GPA 2286)
ISO 10723	Natural gas – Performance evaluation for analytical systems
ISO 10725	General Requirements for the competence of testing and calibration laboratories
Impurities	
ISO 6326-1	Natural gas – Determination of sulfur compounds – Part 1: General introduction
ISO 6326-3	Natural gas – Determination of sulfur compounds – Part 3: Determination of hydrogen sulfide, mercaptan sulfur and carbonyl sulfide sulfur by potentiometry
ISO 6326-5	Natural gas – Determination of Sulfur compounds – Part 5: Lingener combustion method
ISO 6327	Gas analysis – Determination of the water dew point of natural gas – Cooled surface condensation hygrometers
ISO 6570	Natural gas – Determination of potential hydrocarbon liquid content – Gravimetric methods
ISO 6978, part 1, 2 and 3	Natural gas – Determination of mercury
ISO 10101, part 1, 2 and 3	Natural gas – Determination of water by the Karl Fischer method
ISO 11541	Natural gas – Determination of water content at high pressure
ISO 13734	Natural gas – Organic components used as odorants – Requirements and test methods
ISO 19739	Natural gas – Determination of sulfur compounds using gas chromatography
Calculations/conversions of properties	
ISO 80000-1	Quantities and units – Part 1: General
ISO 6578	Specifies the calculations to be made to adjust the volume of a liquid from the conditions at measurement to the equivalent volume of liquid or vapour at a standard temperature and pressure, or to the equivalent mass or energy (calorific content).
ISO 6976	Natural gas – Calculation of calorific values, density, relative density and Wobbe index from composition (refer GPA 2172 and GPA 2145).
ISO 12213-1	Natural gas – Calculation of compression factor – Part 1: Introduction and guidelines

METHOD	**TITLE (alternative method)**
ISO 12213-2	Natural gas – Calculation of compression factor – Part 2: Calculation using molar-composition analysis
ISO 12213-3	Natural gas – Calculation of compression factor – Part 3: Calculation using physical properties
ISO 13443	Natural gas – Standard reference conditions
ISO 15112	Natural gas – energy determination
ISO 15796	Gas Analysıs - Investıgation and treatment of analytical bias
ISO/DIS 20765 –2	Natural gas – Calculation of thermodynamic properties. Part 2: Single-phase properties (gas, liquid, and dense fluid) for extended ranges of application.
Quantity related methods	
ISO 8310	Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels – General requirements for automatic tank thermometers on board marine carriers and floating storage
ISO 8311	Refrigerated light hydrocarbon fluids - Calibration of membrane tanks and independent prismatic tanks in ships – Physical measurement
ISO 10976	Refrigerated light hydrocarbon fluids – Measurement of cargo on board LNG carriers
ISO 18132-1	Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels – General requirements for automatic tank gauges – Part 1: Automatic tank gauges onboard marine carriers and floating storage
ISO 18132-2	Refrigerated light hydrocarbon fluids – General requirements for automatic level gauges – Part 2: Gauges in refrigerated-type shore tanks
ISO 28460	Petroleum and natural gas industries — Installation and equipment for liquefied natural gas — Ship-to-shore interface and port operations

ENCLOSURE 3: OTHER RELEVANT STANDARDS & REFERENCES

1. GPA 2261-2013, Gas chromatography: "Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography"

2. GPA 2172 –2009, Calculation of GHV, Relative Density, Compressibility and theoretical hydrocarbon liquid content for custody transfer

3. GPA 2145 – 2009 , Table of physical properties for hydrocarbons and other compounds of interest to the natural gas industry (to be used with GPA 2172)

4. ASTM D 6667, Standard test method for determination of total volatile sulphur in gaseous hydrocarbons and liquefied petroleum gases by ultraviolet fluorescence

5. ASTM D 1945, Standard test method for analysis of natural gas by gas chromatography

6. HM 21 Calculation procedures for static and dynamic measurement of light hydrocarbon liquids (LNG, LPG, ethylene, propylene and butadienes (replaces IP 251/76)

7. ISO80000-1, Quantities and units, Part 1: General; Annex B Rounding of numbers

8. ASTM E 29 - 13, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

9. General EN standards for LNG facilities:
    - CEN EN 1473 – Installation and equipment of LNG- design of onshore installations
    - EN 1474 – part 1, 2 and 3, installation and equipment for LNG - Design and testing of marine transfer systems

CEN EN ISO 28460 – Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations

10. INCOTERMS 2010, defining duties of seller and buyer among others:
    - FOB – Free on Board (named port of loading)
    - CIF – Cost, Insurance and Freight (named port of discharge)
    - DES – Delivered Ex Ship (port of discharge) (INCOTERMS 2000)

11. JCGM 100:2008 Evaluation of measurement data - Guide to the expression of Uncertainty in Measurement.

JCGN 200:2012 International Vocabulary of metrology. Basic and general concepts and associated terms (VIM)

WEBSITES FOR FURTHER INFORMATION:

- http://www.aga.org: American Gas Association
- http://www.eurogas.org European Natural Gas Companies
- http://www.gie.eu.com: European LNG Terminal operators (> select “gle”)
- http://www.gas.or.jp / http://www.gas.or.jp/english/index.html: Japan Gas Association (JGA)
- http://www.giignl.org information on GIIGNL
- http://www.igu.org information on IGU, the International Gas Union
- http://www.iso.ch information on ISO standards
- http://www.sigtto.org information on SIGTTO LNG shipping and ship-shore best safety practices, with numerous free downloads on safe practices, esp. for LNG ship-shore interface.
- https://easee-gas.eu/#: EASEE-GAS website, with information on common business practices (CBP) in the European natural gas industry, e.g. reference volume, reference temperatures for gas volume and calorific value, harmonized units for calorific value and Wobbe number.
- http://www.naesb.org/: website of the North American Energy Standards Board, with information on common standards in the North American natural gas industry .

ENCLOSURE 4: NOTES ON TERMINOLOGY

- The term “heating value” is synonymous with “calorific value”.
- The qualifiers for calorific value “higher”, “upper”, “total” and “superior” are, for the purposes of this handbook, synonymous with “gross”. Likewise “lower” and “inferior ” are synonymous with “net”.
- The gross calorific value is used generally for LNG trading and widely in the gas industry. Some users of natural gas, notably power generators, prefer the net calorific value which is lower by roughly 10% due to its exclusion of the heat of condensation of the water produced by gas combustion with air.
- “Specific gravity” is synonymous with “relative density”.
- “Wobbe number” is synonymous with “Wobbe index”.
- “Compressibility factor“ is synonymous with “compression factor”.
- “Unloading operation” is synonymous with “discharging operation”

LIST OF FIGURES

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REFERENCES

[1]	Le volume du gaz naturel liquéfié – Association Technique de l'Industrie du Gaz en France - F. Dewerdt et B. Corgier - Janvier 1987.
[2]	Gauge table of the LNG carrier Methania issued by Metrological Service – Brussels.
[3]	Gauge table of the LNG carrier Mourad Didouche issued by the Metrological Service – Paris.
[4]	Calibration of containers and gauges – Journal of the Institute of Petroleum - Volume 58 n°561 – 1972.
[5]	Gas quality – Proceedings of the congress of "Gas Quality Specification and measurement of physical and chemical properties of natural gas" – Groningen The Netherlands 22-25 April 1986 – Edited by GJ van Kossum.
[6]	La masse volumique du gaz natural liquéfié – Association Technique de l'Industrie du Gaz en France - F. Dewerdt – Mars 1980.
[7]	Le pouvoir calorifique du gaz naturel liquéfié, par M. F. Dewerdt – Association Technique de l'Industrie du Gaz en France - Mars 1983.
[8]	LNG measurement – NBSIR 85-3028 - First edition 1985.
[9]	Four mathematical models for the prediction of LNG densities – NBS Technical Note 1030 – December 1980.
[10]	Appendix 2 Information source: Invensys Foxboro, Canada.
[11]	Appendix 7 Information sources: Scientific Instruments, Inc., USA, Kaiser Optical Systems, Inc., USA, and Distrigas of Massachusetts LNG Terminal, Everett (Boston), MA, USA
[12]	Appendix 14 Information sources: Case 1: Fluxys LNG Terminal, Zeebrugge, Belgium; Case 2: presentation at SIGTTO 59th GPC Meeting, 2009-04-22, Boston, MA, USA.
[13]	Appendix 15 Information source: ISO 10976 – working draft # 8
[14]	Figures 11c and 11e: adapted from ISO 8943
[15]	Calculation of carbon dioxide solubility in liquefied natural gas – T. Shen & W. Lin - International Journal of Chemical Engineering and Applications Vol.2, no.5, pp.366-371 – 2011
[16]	Determination of CO_2 solubility in saturated liquid CH_4+N_2 and CH_4+C_2H_6 mixtures above atmospheric pressure – T. Shen, T. Gao, W. Lin & A. Gu – Journal of Chemical Engineering Data vol.57, pp.2296-2803 – 2012
[17]	Experimental determination of CO_2 solubility in liquid CH_4/N_2 mixtures at cryogenic temperatures – T. Gao, T. Shen, W. Lin, A. Gu & Y. Ju – Industrial & Engineering Chemical Research vol.51, pp.9403-2975 - 2012
[18]	M. Richter, R. Kleinrahm, & R. Span. New Apparatus for Accurate Measurement of the Density of Liquefied Natural Gas (LNG). International Gas Union (IGU), IGRC 2011 Proceedings and Presentations Poster Papers - Session 4.
[19]	ISO 5725-2 Accuracy (trueness and precision) of measurement methods and results. Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.
[20]	*Extension of sample sizes and percentage points for significance tests of outlying observations*, Frank E. Grubbs and Glenn Beck. Technometrics Vol. 14, No. 4, November 1972.

APPENDIX 1: USE OF IN-LINE MEASUREMENT OF LNG FLOW

IN-LINE FLOW MEASUREMENT OF LNG

Several types of LNG flow meter exist but LNG ship cargo transfer is conventionally measured by volumetric gauging for custody transfer. However, the question is often asked, can in-line LNG flow measurement be used for custody transfer, or as a check measurement or for allocation purposes ? This section is intended to address that topic.

Performance

It has been demonstrated that both ultrasonic and Coriolis meters can be used for metering LNG at cryogenic temperatures with custody transfer quality repeatability. LNG has an approximate relative density of 0.5 and viscosity of 0.1 cP. From a flow measurement perspective, this application presents few challenges provided the meter can physically handle the cryogenic temperatures and no flashing (2 phase flow) occurs. Testing at a working LNG loading facility has shown that a Coriolis mass meter will agree with an ultrasonic meter on a mass/inferred mass basis within the published uncertainties of both devices. Results from these tests demonstrated repeatability of ±0.125% by mass, a step change improvement in repeatability from ship measurement.

Industry standards already exist for liquid measurement for both Coriolis and ultrasonic liquid meters, although they do not specifically address cryogenic applications. Technology selection can be evaluated based on the pressure loss available and flow rates required. Coriolis meters which measure mass flow directly don't require a density calculation, but have size and pressure drop limitations. Ultrasonic meters require a density calculation (e.g. Klosek-McKinley or Costald), but have no size or pressure drop limitations.

Given the demonstrated performance in LNG service, either technology could be used for allocation or check measurement. It should be noted that one major joint venture is using in-line measurement for allocation (not custody transfer) of LNG produced and commingled in a common storage facility, and two other LNG facilities have installed in-line meters as check meters in order to verify tanker loading measurements.

Proving

With respect to the use of meters for LNG custody transfer, the hurdle is finding an industry accepted practice for proving a meter for use in LNG service. An accepted practice for LNG proving to a traceable standard does not exist at the time of this publication. While in-line meters offer custody transfer quality repeatability in the range of ±0.125% by mass, a meter factor is still required to achieve traceable accuracy. Without a prover, a meter could have a significant biases. LNG proving has several hurdles that must be overcome: compensation for temperature changes, capacity, elimination of boil off, and density changes.

Loading and offloading of ships can involve volumetric rates of 5 000 to 15 000 m^3/hr, so much like gas meters, onsite proving doesn't seem practical, and a feasible concept has yet to be developed. A 0.50°C change in the measured temperature can cause a 0.17% change in the calculated density. These challenges would impact the design of an LNG prover regardless of the physical principles to be employed, e.g. whether it would be based on mass (weight of tank), or volume (tank or piston). Custody transfer using in-line measurement will not become reality until an accepted practice for proving is developed and established in commercial use. Once it has, in-line measurement will be an acceptable alternative or a backup to ship measurement.

APPENDIX 2: LASER TYPE CARGO TANK LEVEL GAUGE

New technology, for information only - see Reference [10].

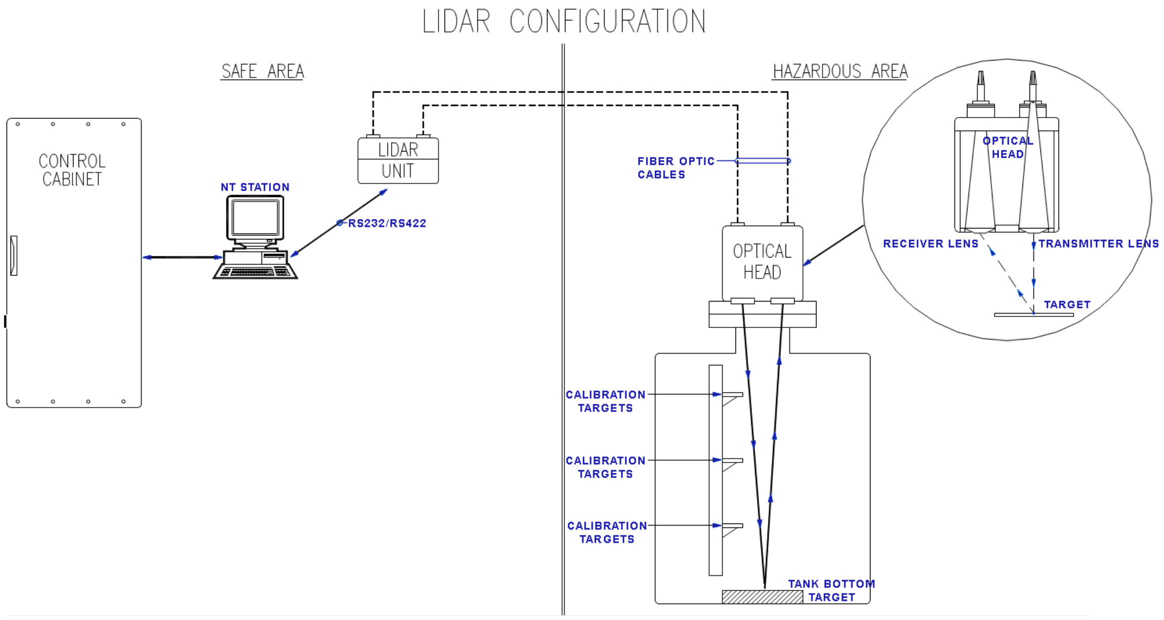


Figure A2.1: Laser type level gauge

Principle

The principle of laser type level gauge is based on a dual transmitter (optical head) composed of an emitter and a receiver, mounted on the top of the cargo tank. The emitter sends a laser beam down towards the surface of the liquid; the signal is reflected from the surface, detected by the receiver cell and send back to the unit control. The system is calibrated at several target levels of the tank.

The first commercial application and certification of this new laser-based technology was in late 2005 following a R&D effort on board the vessel “Le Tellier”. NKKK certification for the system with an accuracy up to ±7.5 mm was granted in November 2005.

Accuracy

Measurement range	:	0 – 50 m
Resolution	:	1 mm
Accuracy	:	±7.5 mm or better

Features

- On-line accuracy verification
- Temperature, pressure, trim and list corrected
- Serial communication
- No in-tank equipment

APPENDIX 3: SOME RECOMMENDATIONS FOR PARTIAL RELOADING OF CARGO TANKS OF LNG CARRIERS, WITH REGARD TO BOTH SAFETY AND CUSTODY TRANSFER ISSUES.

For information only

Introduction and context

In the last decade we have seen a worldwide development of short term and spot cargo LNG trade, involving two new operating trends in LNG shipping:

- LNG Shippers are using LNG carriers for spot cargoes and/or as floating LNG storage,
- several LNG Shippers have considered, and some have carried out, partial unloading and/or partial reloading, i.e. unloading or reloading only one or some of the cargo tanks of the LNG carrier.

When performing such operations, due attention should be given to:

- safe ship/shore operating practices and procedures, and
- proper LNG ship/shore custody transfer procedures.

One of the considerations for safe operating practices and procedures should be to prevent the creation of stratified layers and the risk of a subsequent rollover in the cargo tank(s) involved. Stratification and rollover could occur either when the LNG carrier is alongside the berth of an LNG terminal or alongside another LNG carrier undergoing a partial reloading operation, when at sea, or when unloading its partially loaded LNG cargo in another LNG carrier or at another LNG terminal. In the last case, the risk of stratified layers and subsequent rollover is in the receiving LNG terminal's shore tanks.

With regard to safe operating practices, both GIIGNL and SIGTTO published some rules of good practice in this respect:

- GIIGNL: 'Rollover in LNG Storage Tanks' (1981-1983), Section 3.5 'Stratification and density differences in LNG Ships and Consequences for Shore-based Tanks' (p. 26-27).
- GIIGNL: 'GIIGNL LNG Rollover Study' (update 2014)
- SIGTTO: 'ROLLOVER PREVENTION, A Review of Causes, Methods of Prevention and Damage Limitation Measures' (November 1993), see the paragraph on 'Ship Cargoes' on page 11.
- SIGTTO: 'Guidance for the Prevention of Rollover in LNG Ships', first edition 2012.

Custody Transfer recommendations when considering the reloading of LNG carriers for 'partial reloading' operations

Stratified layers in cargo tanks of LNG carriers can (and have) subsequently resulted in rollover either in the cargo tanks of the LNG carrier or in the receiving on-shore LNG tanks (see Appendix 14).

It should be noted that at the time of writing there is still limited knowledge, reporting and field experience regarding stratification and rollover issues in cargo tanks of LNG carriers. Persistent suggestions that ship movements and sloshing of the LNG cargo would always ensure complete mixing of any stratified layers have been disproved by a few reported cases of stratification and even rollover in cargo tanks of LNG carriers. Therefore all parties acting as prudent and reasonable operators both off-shore and on-shore, should adhere to the following guidelines, particularly with regard to partial loading of cargo tanks.

In view of the above, it should be strongly recommended to first unload a partially filled cargo tank (i.e. a cargo tank filled with more than a minimal heel of only a few % of cargo tank height), and then to reload it with a fresh cargo of LNG.

If an LNG carrier, typically in a spot cargo situation, arrives at an LNG terminal with one or several cargo tanks filled and others empty (perhaps except for a minimal heel), with the intention to load the remaining cargo tanks as well, then prior to agreeing to the LNG carrier's call at that LNG terminal for such a partial reloading operation, the LNG Shipper shall provide the LNG Terminal Operator with an appropriate cargo tank management procedure for such partial reloading of the LNG carrier, thereby ensuring that the following rules for proper custody transfer are strictly adhered to.

Here are a few proposed items for such a procedure.

A. Filling an LNG cargo tank with a heel height exceeding 5% of max. cargo tank filling height shall not be allowed.

B. Likewise, topping up a cargo with LNG transferred from an LNG Terminal tank shall not be allowed. Therefore, before starting a partial loading operation for one or several of the ship's cargo tanks, if necessary each cargo tank in either of the above-mentioned conditions shall first be emptied to the recommended minimum heel level, typically only 0.5 or 1 m of liquid level. Parties should agree on the limits in LNG temperature difference and LNG density difference between the heel and the LNG cargo to be loaded – as default values a maximum acceptable difference of 1°C and 1 kg/m³ respectively between this minimal heel and the loaded cargo are proposed.

C. If an LNG Shipper proposes to call at an LNG terminal with an LNG carrier with one or several cargo tanks full and the others empty (or with a minimum heel), and wishes to reload only the empty cargo tanks, then the following strict guidelines are recommended, to ensure a proper custody transfer both on departure and arrival.

- First of all the Shipper should demonstrate in full detail and in writing that he is able to determine with an overall uncertainty better than 1% (see Section 15) the relevant physical properties of the LNG cargo that is on board the LNG carrier.

- Assuming that the LNG Shipper is able to demonstrate the above, then the parties should verify, based on well established and proven methods, that there is sufficient compatibility between the physical properties of, on the one hand, the LNG cargo onboard in certain cargo tanks, and on the other hand the LNG batch from LNG shore tanks that is to be loaded in the other cargo tanks. As a guidance the following criteria are recommended:

Max. 1 kg/m³ difference in LNG density between the LNG parcels in the ship's cargo tanks
Max. 0.5°C difference in average liquid temperature between the ship's cargo tanks
Max. 50 mbar difference in saturated vapour pressure between the LNG parcels in the ship's cargo tanks. The saturated vapour pressure in each cargo tank shall be calculated with the same method.

- If these criteria cannot be met, then the LNG Shipper should refrain from such a partial reloading operation and first unload all LNG onboard, and next load a fresh and homogeneous cargo of LNG from the shore terminal.

- Likewise, if the LNG batch that is to be reloaded from more than one LNG shore tank, as a guidance the following criteria for these LNG shore tanks are recommended:

Max. 1.0 kg/m³ difference in LNG density between the LNG shore tanks
Max. 0.5°C difference in average liquid temperature between the LNG shore tanks
Max. 50 mbar difference in saturated vapour pressure between the LNG shore tanks; The saturated vapour pressure in each shore tank shall be calculated with the same method.

- One of the purposes of these recommendations is to ensure an accurate custody transfer on unloading, since even small differences in liquid temperature of only a few tenths of a °C between cargo tanks have a detrimental influence on the combined standard uncertainty and overall uncertainty of the calculated energy transferred (see Section 4.1.2 and Section 15).

APPENDIX 4: EXAMPLE OF GAUGE TABLES (see Section 3.1)

TABLE A4-1: EXAMPLE OF GAUGE TABLE WITH ZERO LIST AND TRIM

HEIGHTS m	VOLUMES m^3	HEIGHTS m	VOLUMES m^3	HEIGHTS m	VOLUMES m^3	HEIGHTS m	VOLUMES m^3	HEIGHTS m	VOLUMES m^3
0.00	5.51	0.25	233.02	0.50	464.94	0.75	701.27	1.00	942.01
0.01	14.52	0.26	242.21	0.51	474.31	0.76	710.82	1.01	951.73
0.02	23.54	0.27	251.41	0.52	483.69	0.77	720.37	1.02	961.46
0.03	32.57	0.28	260.62	0.53	493.07	0.78	729.93	1.03	971.20
0.04	41.61	0.29	269.83	0.54	502.46	0.79	739.50	1.04	980.94
0.05	50.66	0.30	279.05	0.55	511.86	0.80	749.07	1.05	990.69
0.06	59.71	0.31	288.28	0.56	521.26	0.81	758.65	1.06	1 000.45
0.07	68.77	0.32	297.52	0.57	530.67	0.82	768.24	1.07	1 010.21
0.08	77.83	0.33	306.76	0.58	540.09	0.83	777.83	1.08	1 019.98
0.09	86.90	0.34	316.01	0.59	549.52	0.84	787.43	1.09	1 029.76
0.10	95.98	0.35	325.26	0.60	558.95	0.85	797.04	1.10	1 039.54
0.11	105.07	0.36	334.52	0.61	568.39	0.86	806.66	1.11	1 049.33
0.12	114.16	0.37	343.79	0.62	577.83	0.87	816.28	1.12	1 059.13
0.13	123.26	0.38	353.07	0.63	587.29	0.88	825.91	1.13	1 068.94
0.14	132.37	0.39	362.36	0.64	596.75	0.89	835.54	1.14	1 078.75
0.15	141.49	0.40	371.65	0.65	606.21	0.90	845.19	1.15	1 088.57
0.16	150.61	0.41	380.94	0.66	615.69	0.91	854.84	1.16	1 098.40
0.17	159.74	0.42	390.25	0.67	625.17	0.92	864.50	1.17	1 108.23
0.18	168.87	0.43	399.56	0.68	634.66	0.93	874.16	1.18	1 118.07
0.19	178.02	0.44	408.88	0.69	644.15	0.94	883.83	1.19	1 127.92
0.20	187.17	0.45	418.21	0.70	653.66	0.95	893.51	1.20	1 137.78
0.21	196.32	0.46	427.54	0.71	663.17	0.96	903.20	1.21	1 147.64
0.22	205.49	0.47	436.88	0.72	672.68	0.97	912.89	1.22	1 157.51
0.23	241.66	0.48	446.23	0.73	682.21	0.98	922.59	1.23	1 167.39
0.24	223.84	0.49	455.58	0.74	691.74	0.99	932.30	1.24	1 177.27

Total volume: 25 577.680 cubic metres.

TABLE A4-2: EXAMPLE OF BOTTOM FINE GAUGE TABLE

HEIGHT	+0 MM	+1 MM	+2 MM	+3 MM	+4 MM	+5 MM	+6 MM	+7 MM	+8 MM	+9 MM
0.10	41.340	41.750	42.160	42.570	42.980	43.390	43.800	44.210	44.620	45.030
0.11	45.440	45.851	46.262	46.673	47.084	47.495	47.906	48.317	48.728	49.139
0.12	49.550	49.962	50.374	50.786	51.198	51.610	52.022	52.434	52.846	53.258
0.13	53.670	51.082	54.494	54.906	55.318	55.730	56.142	56.554	56.966	57.378
0.14	57.790	58.202	58.614	59.026	59.438	59.850	60.262	60.674	61.086	61.498
0.15	61.910	62.323	62.736	63.149	63.562	63.975	64.388	64.801	65.214	65.627
0.16	66.040	66.454	66.868	67.282	67.696	68.110	68.524	68.938	69.352	69.766
0.17	70.180	70.594	71.008	71.422	71.836	72.250	72.664	73.078	73.492	73.906
0.18	74.320	71.734	75.148	75.562	75.976	76.390	76.804	77.218	77.632	78.046
0.19	78.460	78.875	79.290	79.705	80.120	80.535	80.950	81.365	81.780	82.195
0.20	82.610	83.026	83.442	83.858	84.274	84.690	85.106	85.522	85.938	86.354
0.21	86.770	87.186	87.602	88.018	88.434	88.850	89.266	89.682	90.098	90.514
0.22	90.930	91.347	91.764	92.181	92.598	93.015	93.432	93.849	94.266	94.683
0.23	95.100	95.517	95.934	96.351	96.768	98.185	97.602	98.019	98.436	98.853
0.24	99.270	99.688	100.106	100.524	100.942	101.360	101.778	102.196	102.614	103.032
0.25	103.450	103.868	104.286	104.704	105.122	105.540	105.958	106.376	106.794	107.212
0.26	107.630	108.049	108.468	108.887	109.306	109.725	110.144	110.563	110.982	111.401
0.27	111.820	112.239	112.658	113.077	113.496	113.915	114.334	114.753	115.172	115.591
0.28	116.010	116.430	116.850	117.270	117.690	118.110	118.530	118.950	119.370	119.790
0.29	120.210	120.630	121.050	121.470	121.890	122.310	122.730	123.150	123.570	123.990
0.30	124.410	124.831	125.252	125.673	126.094	126.515	126.936	127.357	127.778	128.199
0.31	128.620	129.042	129.464	129.886	130.308	130.730	131.152	131.574	131.996	132.418
0.32	132.840	133.262	133.684	134.106	134.528	134.950	135.372	135.794	136.216	136.638
0.33	137.060	137.482	137.904	138.326	138.748	139.170	139.592	140.014	140.436	140.858
0.34	141.280	141.703	142.126	142.549	142.972	143.395	143.818	144.241	144.664	145.087
0.35	145.510	145.934	146.358	146.782	147.206	147.630	148.054	148.478	148.902	149.326
0.36	149.750	150.174	150.598	151.022	151.446	151.870	152.294	152.718	153.142	153.566
0.37	153.990	154.414	154.838	155.262	155.686	156.110	156.534	156.958	157.382	157.806
0.38	158.230	158.655	159.080	159.505	159.930	160.355	160.780	161.205	161.630	162.055
0.39	162.480	162.906	163.332	163.758	164.184	164.610	165.036	165.462	165.888	166.314
0.40	166.740	167.166	167.592	168.018	168.444	168.870	169.296	169.722	170.148	170.574
0.41	171.000	171.427	171.854	172.281	172.708	173.135	173.562	173.989	174.416	174.843
0.42	175.270	175.697	176.124	176.551	176.978	177.405	177.832	178.259	178.686	179.113
0.43	179.540	179.968	180.396	180.824	181.252	181.680	182.108	182.536	182.964	183.392
0.44	183.820	184.248	184.676	185.104	185.532	185.960	186.388	186.816	187.244	187.672
0.45	188.100	188.529	188.958	189.387	189.816	190.245	190.674	191.103	191.532	191.961
0.46	192.390	192.819	193.248	193.677	194.106	194.535	194.964	195.393	195.822	196.251
0.47	196.680	197.110	197.540	197.970	198.400	198.830	199.260	199.690	200.120	200.550
0.48	200.980	201.410	201.840	202.270	202.700	203.130	203.560	203.990	204.420	204.850
0.49	205.280	205.711	206.142	206.573	207.004	207.435	207.866	208.297	208.728	209.159
0.50	209.590	210.022	210.454	210.886	211.318	211.750	212.182	212.614	213.046	213.478
0.51	213.910	214.341	214.772	215.203	215.634	216.065	216.496	216.927	217.358	217.789
0.52	218.220	218.653	219.086	219.519	219.952	220.385	220.818	221.251	221.684	222.117
0.53	222.550	222.983	223.416	223.849	224.282	224.715	225.148	225.581	226.014	226.447
0.54	226.880	227.313	227.746	228.179	228.612	229.045	229.478	229.911	230.344	230.777
0.55	231.210	231.644	232.078	232.512	232.946	233.380	233.814	234.248	234.682	235.116
0.56	235.550	235.985	236.420	236.855	237.290	237.725	238.160	238.595	239.030	239.465
0.57	239.900	240.335	240.770	241.205	241.640	242.075	242.510	242.945	243.380	243.815
0.58	244.250	244.686	245.122	245.558	245.994	246.43	246.866	247.302	247.738	248.174
0.59	248.610	249.046	249.482	249.918	250.354	250.790	251.226	251.662	252.098	252.534

Heights are in metres, volumes in cubic metres.

TABLE A4-3: EXAMPLE OF TOP FINE GAUGE TABLE

HEIGHT	+0 MM	+1 MM	+2 MM	+3 MM	+4 MM	+5 MM	+6 MM	+7 MM	+8 MM	+9 MM
21.75	26021.430	26022.439	26023.448	26024.457	26025.466	26026.475	26027.484	26028.493	26029.502	26030.511
21.76	26031.520	26032.527	26033.534	26034.541	26035.548	26036.555	26037.562	26038.569	26039.576	26040.583
21.77	26041.590	26042.598	26043.606	26044.614	26045.622	26046.630	26047.638	26048.646	26049.654	26050.662
21.78	26051.670	26052.675	26053.680	26054.685	26055.690	26056.695	26057.700	26058.705	26059.710	26060.715
21.79	26061.720	26062.726	26063.732	26064.738	26065.744	26066.750	26067.756	26068.762	26069.768	26070.774
21.80	26071.780	26072.786	26073.792	26074.798	26075.804	26076.810	26077.816	26078.822	26079.828	26080.834
21.81	26081.840	26082.843	26083.846	26084.849	26085.852	26086.855	26087.858	26088.861	26089.864	26090.867
21.82	26091.870	26092.873	26093.876	26094.879	26095.882	29096.885	26097.888	26098.891	26099.894	26100.897
21.83	26101.900	26102.903	26103.906	26104.909	26105.912	26106.915	26107.918	26108.921	26109.924	26110.927
21.84	26111.930	26112.932	26113.934	26114.936	26115.938	26116.940	26117.942	26118.944	26119.946	26120.948
21.85	26121.950	26122.951	26123.952	26124.953	26125.954	26126.955	26127.956	26128.957	26129.958	26130.959
21.86	26131.960	26132.961	26133.962	26134.963	26135.964	26136.965	26137.966	26138.967	26139.968	26140.969
21.87	26141.970	26142.969	26143.968	26144.967	26145.966	26146.965	26147.964	26148.963	26149.962	26150.961
21.88	26151.960	26152.959	26153.958	26154.957	26155.956	26156.955	26157.954	26158.953	26159.952	26160.951
21.89	26161.950	26162.950	26163.950	26164.950	26165.950	26166.950	26167.950	26168.950	26169.950	26170.950
21.90	26171.950	26172.947	26173.944	26174.941	26175.938	26176.935	26177.932	26178.929	26179.926	26180.923
21.91	26181.920	26182.918	26183.916	26184.914	26185.912	26186.910	26187.908	26188.906	26189.904	26190.902
21.92	26191.900	26192.896	26193.892	16194.888	26195.884	26196.880	26197.876	26198.872	26199.868	26200.864
21.93	26201.860	26202.855	26203.850	26204.845	26205.840	26206.835	26207.830	26208.825	26209.820	26210.815
21.94	26211.810	26212.806	26213.802	26214.798	26215.794	26216.790	26217.786	26218.782	26219.778	26220.774
21.95	26221.770	26222.763	26223.756	26224.749	26225.742	26226.735	26227.728	26228.721	26229.714	26230.707
21.96	26231.700	26232.693	26233.686	26234.679	26235.672	26236.665	26237.658	26238.651	26239.644	26240.637
21.97	26241.630	26242.624	26243.618	26244.613	26245.606	26246.600	26247.594	26248.588	26249.582	26250.576
21.98	26251.570	26252.562	26253.554	26254.546	26255.538	26256.530	26257.522	26258.514	26259.506	26260.498
21.99	26261.490	26262.480	26263.470	26264.460	26265.450	26266.440	26267.430	26268.420	26269.410	26270.400
22.00	23271.390	26272.383	26273.376	26274.369	26275.362	26276.355	26277.348	26278.341	26279.334	26280.327
22.01	26281.320	26282.309	26283.298	26284.287	26285.276	26286.265	26287.254	26288.243	26289.232	26290.221
22.02	26291.210	26292.200	26293.190	26294.180	26295.170	26296.160	26297.150	26298.140	26299.130	26300.120
22.03	26301.110	26302.098	26303.086	26304.074	26305.062	26306.050	26307.038	26308.026	26309.014	26310.002
22.04	26310.990	26311.978	26312.966	26313.954	26314.942	26315.930	26316.918	26317.906	26318.894	26319.882
22.05	26320.870	26321.858	26322.846	26323.834	26324.822	26325.810	26326.798	26327.786	26328.774	26329.762
22.06	26330.750	26331.736	26332.722	26333.708	26334.694	26335.680	26336.666	26337.652	26338.638	26339.624
22.07	26340.610	26341.595	26342.580	26343.565	26344.550	26345.535	26346.520	26347.505	26348.490	26349.475
22.08	26350.460	26351.446	26352.432	26353.418	26354.404	26355.390	26356.376	26357.362	26358.348	26359.334
22.09	26360.320	26361.304	26362.288	26363.272	26364.256	26365.240	26366.224	26367.208	26368.192	26369.176
22.10	26370.160	26371.144	26372.128	26373.112	26374.096	26375.080	26376.064	26377.048	26378.032	26379.016
22.11	26380.000	26380.984	26381.968	26382.952	26383.936	26384.920	26385.904	26386.888	26387.872	26388.856
22.12	26389.840	26390.821	26391.802	26392.783	26393.764	26394.745	26395.726	26396.707	26397.688	26398.669
22.13	26399.650	26400.631	26401.612	26402.593	26403.574	26404.555	26405.536	26406.517	26407.498	26408.479
22.14	26409.460	26410.442	26411.424	26412.406	26413.388	26414.370	26415.352	26416.334	26417.316	26418.298
22.15	26419.280	26420.260	26421.240	26422.220	26423.200	26424.180	26425.160	26426.140	26427.120	26428.100
22.16	26429.080	26430.060	26431.040	26432.020	26433.000	26433.980	26434.960	26435.940	26436.920	26437.900
22.17	26438.880	26439.858	26440.836	26441.814	26442.792	26443.770	26444.748	26445.726	26446.704	26447.682
22.18	26448.660	26449.638	26450.616	26451.594	26452.572	26453.550	26454.528	26455.506	26456.484	26457.462
22.19	26458.440	26459.418	26460.396	26461.374	26462.352	26463.330	26464.308	26465.286	26466.264	26467.242
22.20	26468.220	26469.196	26470.172	26471.148	26472.124	26473.100	26474.076	26475.052	26476.028	26477.004
22.21	26477.980	26478.955	26479.930	26480.905	26481.880	26482.855	26483.830	26484.805	26485.780	26486.755
22.22	26487.730	26488.707	26489.684	26490.661	26491.630	26492.615	26493.592	26494.569	26495.546	26496.523
22.23	26497.500	26498.473	26499.446	26500.419	26501.392	26502.365	26503.338	26504.311	26505.284	26506.257

Heights are in metres, volumes in cubic metres.

TABLE A4-4: EXAMPLE OF VOLUME CORRECTIONS ACCORDING TO TANK SERVICE TEMPERATURES FOR SELF SUPPORTING TANKS

$$V_t = K \cdot V_{-160°C}$$

T (°C)	K	T (°C)	K
-165.0	0.99980	-160.8	0.99997
-164.9	0.99980	-160.7	0.99997
-164.8	0.99981	-160.6	0.99998
-164.7	0.99981	-160.5	0.99998
-164.6	0.99981	-160.4	0.99998
-164.5	0.99982	-160.3	0.99999
-164.4	0.99982	-160.2	0.99999
-164.3	0.99983	-160.1	1.00000
-164.2	0.99983	-160.0	1.00000
-164.1	0.99983	-159.9	1.00000
-164.0	0.99984	-159.8	1.00001
-163.9	0.99984	-159.7	1.00001
-163.8	0.99985	-159.6	1.00002
-163.7	0.99985	-159.5	1.00002
-163.6	0.99985	-159.4	1.00002
-163.5	0.99986	-159.3	1.00003
-163.4	0.99986	-159.2	1.00003
-163.3	0.99987	-159.1	1.00004
-163.2	0.99987	-159.0	1.00004
-163.1	0.99987	-158.9	1.00005
-163.0	0.99988	-158.8	1.00005
-162.9	0.99988	-158.7	1.00005
-162.8	0.99989	-158.6	1.00006
-162.7	0.99989	-158.5	1.00006
-162.6	0.99989	-158.4	1.00007
-162.5	0.99990	-158.3	1.00007
-162.4	0.99990	-158.2	1.00008
-162.3	0.99991	-158.1	1.00008
-162.2	0.99991	-158.0	1.00008
-162.1	0.99991	-157.9	1.00009
-162.0	0.99992	-157.8	1.00009
-161.9	0.99992	-157.7	1.00010
-161.8	0.99993	-157.6	1.00010
-161.7	0.99993	-157.5	1.00010
-161.6	0.99993	-157.4	1.00011
-161.5	0.99994	-157.3	1.00011
-161.4	0.99994	-157.2	1.00012
-161.3	0.99995	-157.1	1.00012
-161.2	0.99995	-157.0	1.00013
-161.1	0.99995	-156.9	1.00013
-161.0	0.99996	-156.8	1.00013
-160.9	0.99996	-156.7	1.00014

APPENDIX 5: EXAMPLE OF VOLUME CALCULATION (see Section 3.3)

TABLE A5-1: VOLUME DETERMINATION BEFORE LOADING LNG

LNG CARRIER
VOYAGE No.
CARGO DENSITY: 451.61 kg/m^3
TRIM: +80 cm (AFT)
LIST ANGLE: -0.5 ° (PORT)
BERTH:

CARGO ON BOARD AT ARRIVAL
SURVEY DATE:
SURVEY TIME GMT:
LOCAL TIME:
REMARKS:

	Vapour temp. °C (1)	Level gauge reading mm	Corrections					Corrected height mm (7)	Liquid Volume m^3 (8)
			Shrink. mm (2)	Density mm (3)	List mm (4)	Trim mm (5)	Overall mm (6)		
TANK 1	-117.22	575	+42	+2	+4	-30	+18	593	249.918
TANK 2	-124.32	435	+44	+2	+4	-51	-1	434	425.150
TANK 3	-125.16	458	+44	+2	+4	-56	-6	452	509.560
TANK 4	-124.63	505	+44	+2	+4	-56	-6	499	563.084
TANK 5	-122.46	543	+44	+2	+4	-54	-4	539	502.460
						TOTAL O/B			2 250.172

Notes:

(1) *For measurement of temperature in the gaseous phase, see Section 4.2.*

(2) *Correction for ribbon shrinkage of the float level gauge due to the cryogenic temperature in the gaseous phase according to Table A5-3. The correction shrink is generally referred to as tape correction. On Moss ships, there is also a correction called shrinkage factor.*

(3) Correction for LNG density, established from the density calculated on the basis of the LNG composition, according to Table A5-4.

(4) Correction for the list corresponding to the liquid height according to the correction tables, an example of which is shown in Table A5-5 for tank No. 1. In this case the position of the gauge is at the starboard side of the ship's centre line.

(5) Correction for the trim corresponding to the liquid height according to the correction tables, an example of which is shown in Table A5-6 for tank No. 1 (an interpolation was made in this case between the correction values for a 50 cm and a 100 cm trim). In this case the position of the gauge is on the stern-side of the sideline of the tank.

(6) Algebraic sum of corrections (2), (3), (4) and (5).

(7) Corrected height resulting from the algebraic sum of the five previous columns.

*(8) Determination of the liquid volume given in the calibration tables from the corrected height. These tables are established for heights varying mm by mm, see example in Table A4-1 (*Appendix 4*) on the basis of certified tables indicating volumes for heights varying cm by cm. An example is given in Table A4-2* (Appendix 4) *for the empty tank No. 1 and in Table A4-3* (Appendix 4) *for the full tank No. 2.*

TABLE A5-2: VOLUME DETERMINATION AFTER LOADING LNG

LNG CARRIER
VOYAGE No.
CARGO DENSITY: 450.90 kg/m^3
TRIM: +50 cm (AFT)
LIST ANGLE: 0 °
BERTH:

CARGO ON BOARD AT DEPARTURE
SURVEY DATE:
SURVEY TIME GMT:
LOCAL TIME:
REMARKS:

	Vapour temp. °C (1)	Level gauge reading mm	Corrections					Corrected height mm (7)	Liquid Volume m^3 (8)
			Shrink. mm (2)	Density mm (3)	List mm (4)	Trim mm (5)	Overall mm (6)		
TANK 1	-152.00	22 040	1	2	0	-19	-16	22 024	12 833.320
TANK 2	-152.00	22 123	1	2	0	-32	-29	22 094	26 364.256
TANK 3	-152.00	22 138	1	2	0	-35	-32	22 106	29 914.104
TANK 4	-156.00	22 165	1	2	0	-35	-32	22 133	29 962.222
TANK 5	-156.00	22 150	1	2	0	-34	-31	22 119	25 210.599
						TOTAL O/B dep.			124 284.501
						TOTAL O/B arr.			2 250.172
				% Cargo on board: 98		TOTAL loaded			122 034.329

Notes (1) to (8): see table above.

TABLE A5-3: EXAMPLE OF GAUGE CORRECTIONS FOR LOW TEMPERATURES

VAPOUR TEMP METRES	-165C° mm	-160C° mm	-155C° mm	-150C° mm	-145C° mm	-140C° mm	-135C° mm	-130C° mm	-125C° mm	-120C° mm	-115C° mm	-110C° mm
0.250	56	55	54	52	51	49	48	46	45	43	42	40
0.500	56	54	53	52	50	49	47	46	44	43	42	40
0.750	55	54	52	51	50	48	47	45	44	43	41	40
1.000	55	53	52	50	49	48	46	45	43	42	41	39
1.250	54	53	51	50	49	47	46	44	43	42	40	39
1.500	53	52	51	49	48	47	45	44	42	41	40	38
1.750	53	51	50	49	47	46	45	43	42	41	39	38
2.000	52	51	49	48	47	46	44	43	41	40	39	37
2.250	51	50	49	48	46	45	44	42	41	40	38	37
2.500	51	50	48	47	46	44	43	42	41	39	38	36
2.750	50	49	48	46	45	44	43	41	40	39	37	36
3.000	50	48	47	46	45	43	42	41	40	38	37	36
3.250	49	48	47	45	44	43	42	40	39	38	36	35
3.500	48	47	46	45	44	42	41	40	39	37	36	35
3.750	48	47	45	44	43	42	41	39	38	37	36	34
4.000	47	46	45	44	42	41	40	39	38	36	35	34
4.250	47	45	44	43	42	41	39	38	37	36	35	33
4.500	46	45	44	42	41	40	39	38	37	35	34	33
4.750	45	44	43	42	41	40	38	37	36	35	34	32
5.000	45	44	42	41	40	39	38	37	36	34	33	32
5.250	44	43	42	41	40	38	37	36	35	34	33	32
5.500	43	42	41	40	39	38	37	36	35	33	32	31
5.750	43	42	41	40	38	37	36	35	34	33	32	31
6.000	42	41	40	39	38	37	36	35	34	32	31	30
6.250	42	41	39	38	37	36	35	34	33	32	31	30
6.500	41	40	39	38	37	36	35	34	33	32	30	29
6.750	40	39	38	37	36	35	34	33	32	31	30	29
7.000	40	39	38	37	36	35	34	33	32	31	30	28
7.250	39	38	37	36	35	34	33	32	31	30	29	28
7.500	38	37	37	36	35	34	33	32	31	30	29	28
7.750	38	37	36	35	34	33	32	31	30	29	28	27
8.000	37	36	35	34	33	33	32	31	30	29	28	27
8.250	37	36	35	34	33	32	31	30	29	28	27	26
8.500	36	35	34	33	32	31	31	30	29	28	27	26
8.750	35	34	34	33	32	31	30	29	28	27	26	25
9.000	35	34	33	32	31	30	29	29	28	27	26	25
9.250	34	33	32	32	31	30	29	28	27	26	25	24
9.500	33	33	32	31	30	29	28	28	27	26	25	24
9.750	33	32	31	30	30	29	28	27	26	25	24	24
10.000	32	31	31	30	29	28	27	27	26	25	24	23
10.250	32	31	30	29	28	28	27	26	25	24	24	23
10.500	31	30	29	29	28	27	26	26	25	24	23	22
10.750	30	30	29	28	27	27	26	25	24	23	23	22
11.000	30	29	28	28	27	26	25	24	24	23	22	21
11.250	29	28	28	27	26	25	25	24	23	22	22	21
11.500	29	28	27	26	26	25	24	23	23	22	21	20
11.750	28	27	27	26	25	24	24	23	22	22	21	20
12.000	27	27	26	25	25	24	23	22	22	21	20	20
12.250	27	26	25	25	24	23	23	22	21	21	20	19
12.500	26	25	25	24	23	23	22	21	21	20	19	19

TABLE A5-4: FLOAT GAUGES – EXAMPLE OF FLOAT BUOYANCY / DIP CORRECTIONS

The float gauges have been adjusted to read correctly with the float floating in LNG of a density of 470 kg/m^3.

The following table gives corrections to apply to the float gauge readings when floating in liquids of densities other than 470 kg/m^3.

DENSITY (kg/m^3)	CORRECTIONS (mm)
450 - 452	+2
453 - 462	+1
463 - 472	0
473 - 482	-1
483 - 493	-2
494 - 505	-3
506 - 516	-4
517 - 529	-5
530 - 542	-6
543 - 550	-7

TABLE A5-5: EXAMPLE OF LIST CORRECTION TABLE

	LIST ANGLE (°)											
HEIGHTS	**-3.0**	**-2.5**	**-2.0**	**-1.5**	**-1.0**	**-0.5**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**
0.51	0.034	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.006
0.52	0.034	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
0.53	0.033	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
0.57	0.033	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
0.58	0.033	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.008
0.81	0.033	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.008
0.82	0.033	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
0.88	0.033	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
0.89	0.034	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.01	0.034	0.026	0.019	0.013	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.02	0.034	0.026	0.019	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.05	0.034	0.026	0.019	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.06	0.034	0.026	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.36	0.034	0.026	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.37	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.43	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.008	-0.007
1.44	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.007	-0.007
1.47	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.008	-0.007	-0.007
1.48	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.007	-0.007	-0.007
1.59	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.007	-0.007	-0.007
1.60	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.007	-0.007	-0.006
1.68	0.034	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.007	-0.007	-0.006
1.69	0.035	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.007	-0.007	-0.006
2.29	0.035	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.007	-0.007	-0.007	-0.006
2.30	0.035	0.027	0.020	0.014	0.008	0.004	-0.003	-0.005	-0.006	-0.007	-0.007	-0.006

The list angles are in degrees, negative values to port, and positive values to starboard.
Heights and corrections are in metres.

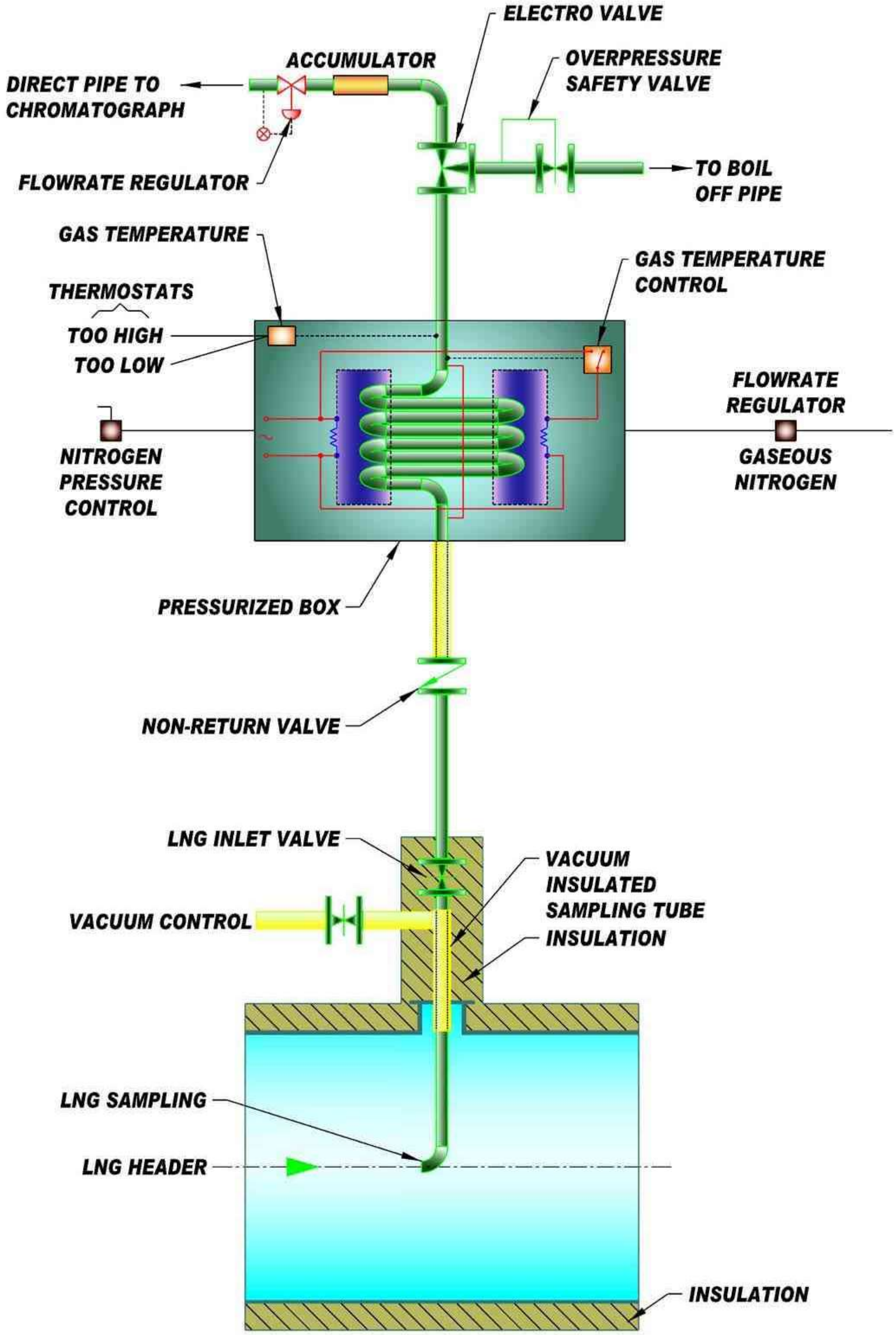
TABLE A5-6: EXAMPLE OF TRIM CORRECTION TABLE

TRIM							
HEIGHTS	**-2.00**	**-1.50**	**-1.00**	**-0.50**	**0.50**	**1.00**	**1.50**
0.55	0.077	0.057	0.038	0.019	-0.019	-0.038	-0.057
0.56	0.077	0.057	0.038	0.019	-0.019	-0.038	-0.057
0.59	0.077	0.057	0.038	0.019	-0.019	-0.038	-0.057
0.60	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.61	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.62	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.67	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.68	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.72	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.73	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.78	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.79	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.80	0.077	0.058	0.038	0.019	-0.019	-0.038	-0.057
0.81	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.057
0.82	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.057
0.83	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.057
0.84	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.057
0.85	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.057
0.86	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.057
0.87	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.058
0.89	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.058
0.90	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.058
0.92	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.058
0.93	0.077	0.058	0.039	0.019	-0.019	-0.038	-0.058
0.94	0.077	0.058	0.039	0.019	-0.019	-0.039	-0.058

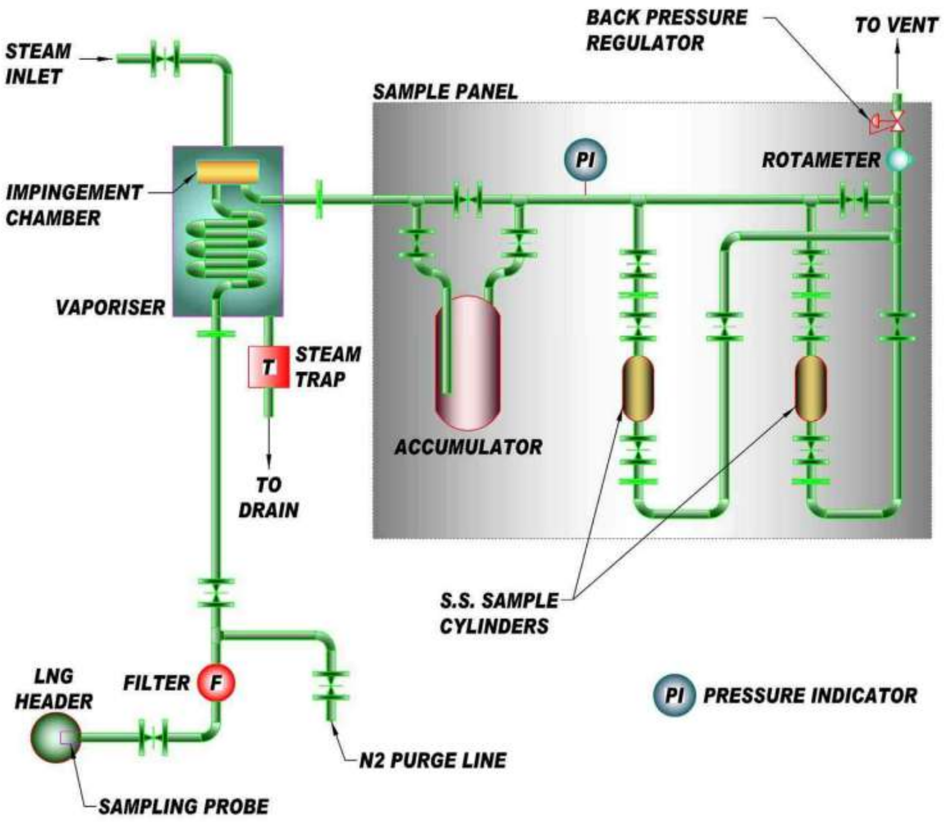
The trim values are in metres, negative values fore, positive values aft.
The heights and the corrections are in metres.

APPENDIX 6: EXAMPLES OF DISCONTINUOUS AND CONTINUOUS SAMPLING AND VAPORIZATION SYSTEMS

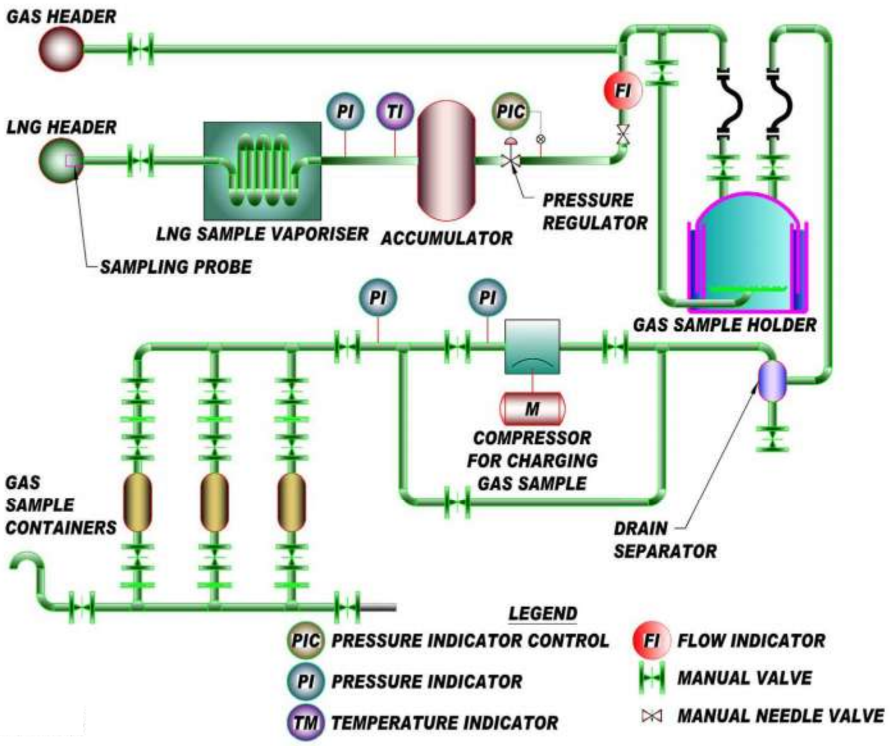
a) LNG sampling system with electric LNG vaporizer



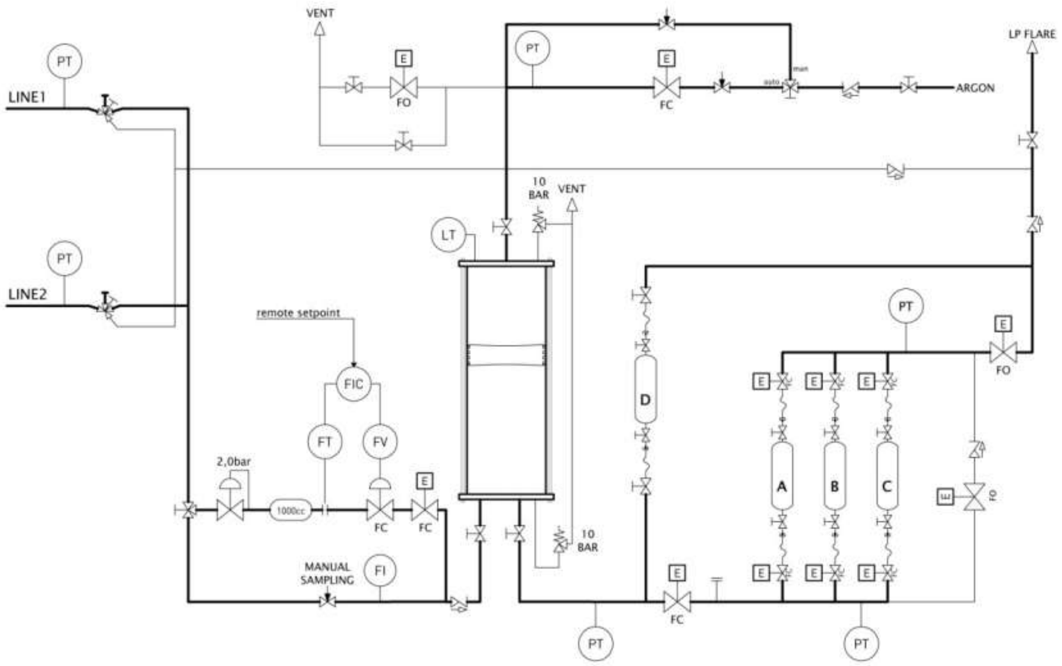
b) LNG sampling system with steam vaporizer



c) Continuous sampling system with compressor for charging gas sample containers



d) Continuous sampling system with pressurized argon gas for emptying sampling vessel and filling gas sample containers



APPENDIX 7: DIRECT IN-LINE ANALYSIS WITH RAMAN SPECTROSCOPY

New technology, for information only, see reference [11]

The Technology

Raman spectroscopy is a form of vibration spectroscopy where a material of interest is illuminated by a highly monochromatic light source, typically a laser, and the resulting scattered light is analyzed. When light interacts with a molecule, most photons are elastically scattered. The scattered photons have the same energy (frequency) and, therefore wavelength (colour) as the incident photons. However, a small fraction of light (approximately 1 in 10^8 photons) is scattered at optical frequencies different from, and usually lower than, the frequency of the incident photons. The process leading to this inelastic scatter is termed the Raman effect, discovered in 1928 by Indian physicist Chandrasekhara Venkata Raman who was awarded the Nobel Prize for physics in 1930.

The energy of a molecular vibration mode depends on the molecular structure of the material. A Raman spectrum is, in effect, a “molecular fingerprint” unique to that compound (see Figure A7.1). The spectrum can be analyzed to obtain information on the molecular components of the material being illuminated as well as their relative abundance. The signal strength is strongly dependent on the density of the sample so it is advantageous to measure the liquid directly. This also avoids the need for the phase change or molecular separation common with other analytical methods. Due to the fact that the Raman effect is a relatively weak process, with the currently available technology it is typically not suitable for trace (low ppm) analysis of higher (C7+) components in LNG.

The Adaptation to LNG

For LNG analysis a cryogenic optical probe and an internal calibration process were developed. The latter allows the analyser to perform diagnostics automatically.

Via a fibre optic cable and the optical probe the laser light is introduced into the LNG pipeline through a sapphire window at the end of the probe. The actual molecular excitation takes place approximately 300 to 400 microns off the window. As there is no “wet chemistry” taking place there is no need for cleaning the device or other regular maintenance issues. The probe contains a series of optical components for filtering the light and is connected to a base unit by a length of fibre optic cable.

The fibre optic cable is terminated in the analyser base unit which can be installed in the field or inside a technical building, e.g. a process control room. An initial calibration of the equipment is performed at the factory prior to shipment. Once installed on site, a simple calibration of the fibre transmission intensity is all the calibration that is needed. Analyser maintenance typically occurs on an annual basis.

Laboratory and LNG field testing allowed for the development of a mathematical model to convert the Raman spectrum to a composition and energy content. This model will be enhanced as additional field data is gathered, thus eliminating the variation that results from individual calibrations of current composition analysis systems that are required by gas chromatographs.

Field Testing

Data was collected on several LNG carrier unloading operations. The results of the measurements indicated that 2-sigma repeatability is better than 0.1 BTU and accuracy is better than 0.5 BTU when compared to gas chromatographic data taken at the same time (see Figure A7.2). After analysis, the bulk of the 0.5 BTU offset appears to be due to the BTU value assigned by the chromatograph to C_{6+} components, which are not (yet) incorporated in the current Raman Model.

Future model refinements, which will include the effects of the C_{6+} components should be able to close the offset. This may be further improved through the use of a more sophisticated model that incorporates more extensive field and laboratory analysis.

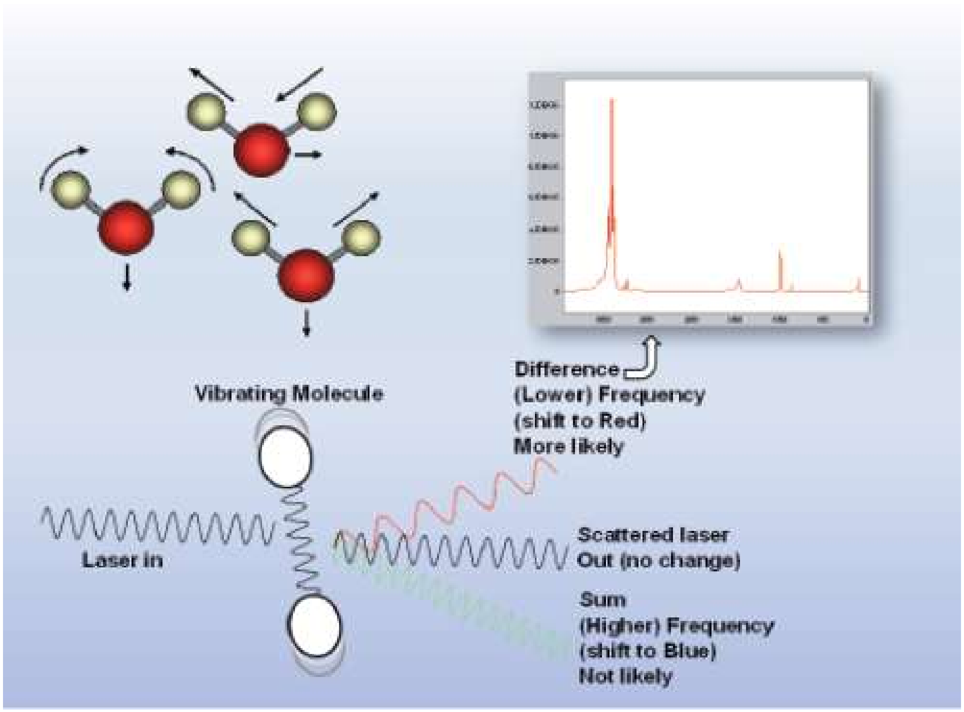


Figure A7.1 - Graphical representation of the Raman effect.

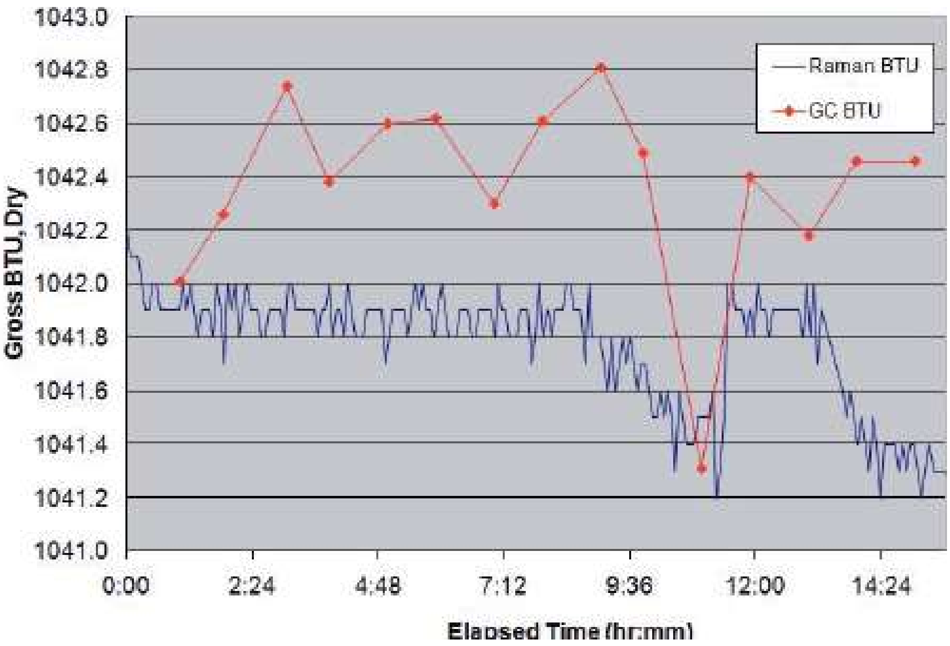


Figure A7.2 - GC and Raman BTU data comparison for a ship unloading.

APPENDIX 8: Grubbs' test [19] and [20]

Grubbs' test is specified in ISO 5725-2 standard, as follows:

One outlying observation

Given a set of data x_i for i = 1, 2, …, p, arranged in ascending order, to determine whether the largest observation is an outlier using Grubbs' test, compute the Grubb's statistic, Gp:

$$G_p = \left(x_p - \bar{x}\right)/s$$

where

$$\bar{x} = \frac{1}{p}\sum_{i=1}^{p} x_i$$

and

$$s = \sqrt{\frac{1}{p-1}\sum_{i=1}^{p}(x_i - \bar{x})^2}$$

To test the significance of the smallest observation, compute the test statistic G1:

$$G_1 = (\bar{x} - x_1)/s$$

a) If the test statistic is less than or equal to its 5 % critical value, the item tested is accepted as correct.
b) If the test statistic is greater than its 5 % critical value and less than or equal to its 1 % critical value, the item tested is called a straggler and is indicated by a single asterisk.
c) If the test statistic is greater than its 1 % critical value, the item is called a statistical outlier and is indicated by a double asterisk.

Two outlying observations

To test whether the two largest observations may be outliers, compute the Grubbs' test statistic G:

$$G = s_{p-1,p}^2/s_0^2$$

where

$$s_0^2 = \sum_{i=1}^{p}(x_i - \bar{x})^2$$

and

$$s_{p-1,p}^2 = \sum_{i=1}^{p-2}\left(x_i - \bar{x}_{p-1,p}\right)^2$$

and

$$\bar{x}_{p-1,p} = \frac{1}{p-2}\sum_{i=1}^{p-2} x_i$$

Alternatively, to test the two smallest observations, compute the Grubbs' test statistic G:

$$G = s_{1,2}^2/s_0^2$$

where

$$s_{1,2}^2 = \sum_{i=3}^{p}\left(x_i - \bar{x}_{1,2}\right)^2$$

and

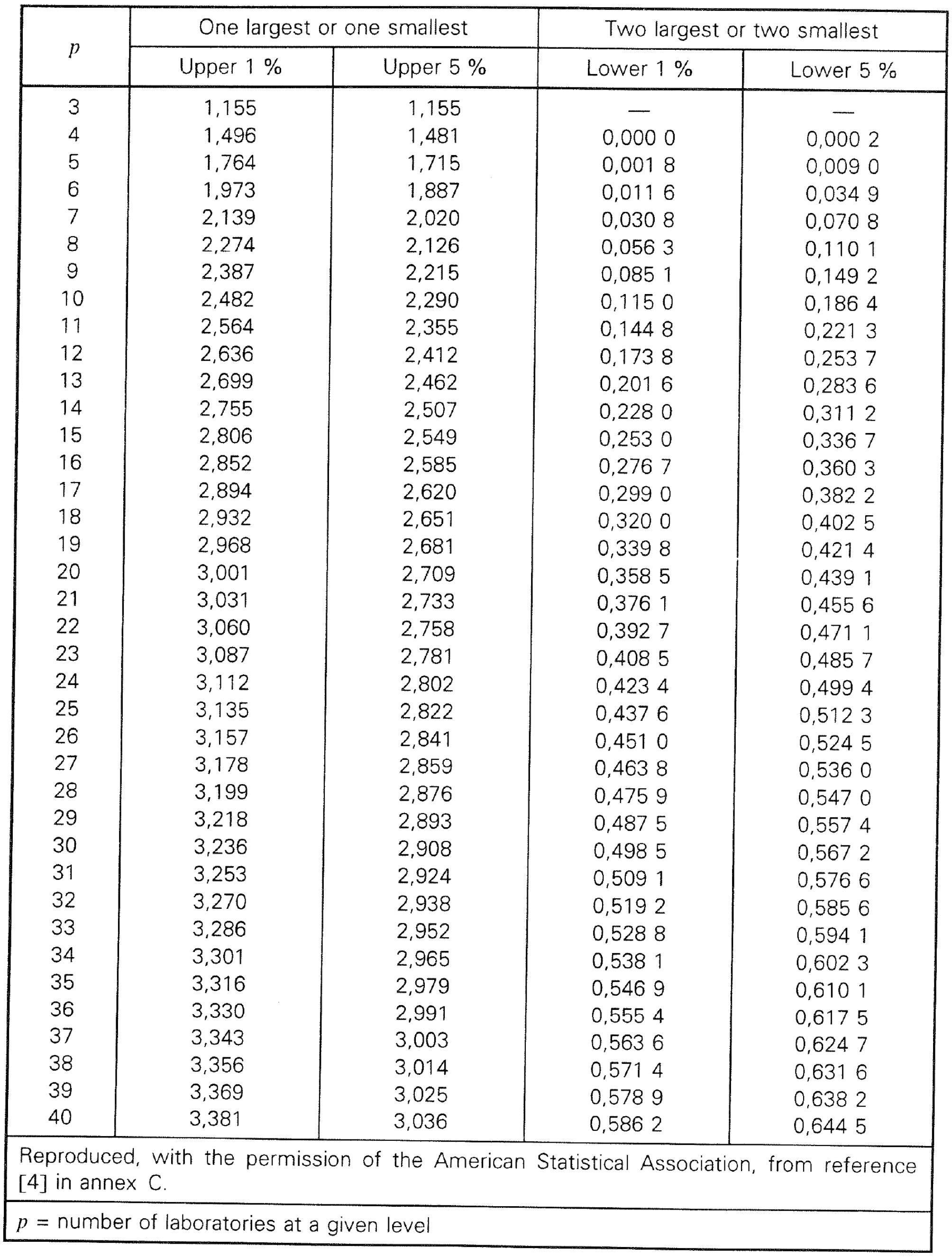
$$\bar{x}_{1,2} = \frac{1}{p-2}\sum_{i=3}^{p} x_i$$

Critical values for the Grubbs' test are given in table 5 of ISO 5725-2 (see table A8-1).

Application of Grubbs' test

When analysing a precision experiment, Grubbs' test can be applied as follows:
Apply the Grubbs' test for one outlying observation. If it is shown to be an outlier, exclude it, and repeat the test at the other extreme (e.g. if the highest is an outlier then look at the lowest with the highest excluded), but do not apply the Grubbs' test for two outlying observations. If the Grubbs' test does not show any observation to be an outlier, then apply the double-Grubbs' test.

Table A8-1: Critical values for Grubbs' test (ISO 5725-2)



p	One largest or one smallest		Two largest or two smallest	
	Upper 1 %	Upper 5 %	Lower 1 %	Lower 5 %
3	1,155	1,155	—	—
4	1,496	1,481	0,000 0	0,000 2
5	1,764	1,715	0,001 8	0,009 0
6	1,973	1,887	0,011 6	0,034 9
7	2,139	2,020	0,030 8	0,070 8
8	2,274	2,126	0,056 3	0,110 1
9	2,387	2,215	0,085 1	0,149 2
10	2,482	2,290	0,115 0	0,186 4
11	2,564	2,355	0,144 8	0,221 3
12	2,636	2,412	0,173 8	0,253 7
13	2,699	2,462	0,201 6	0,283 6
14	2,755	2,507	0,228 0	0,311 2
15	2,806	2,549	0,253 0	0,336 7
16	2,852	2,585	0,276 7	0,360 3
17	2,894	2,620	0,299 0	0,382 2
18	2,932	2,651	0,320 0	0,402 5
19	2,968	2,681	0,339 8	0,421 4
20	3,001	2,709	0,358 5	0,439 1
21	3,031	2,733	0,376 1	0,455 6
22	3,060	2,758	0,392 7	0,471 1
23	3,087	2,781	0,408 5	0,485 7
24	3,112	2,802	0,423 4	0,499 4
25	3,135	2,822	0,437 6	0,512 3
26	3,157	2,841	0,451 0	0,524 5
27	3,178	2,859	0,463 8	0,536 0
28	3,199	2,876	0,475 9	0,547 0
29	3,218	2,893	0,487 5	0,557 4
30	3,236	2,908	0,498 5	0,567 2
31	3,253	2,924	0,509 1	0,576 6
32	3,270	2,938	0,519 2	0,585 6
33	3,286	2,952	0,528 8	0,594 1
34	3,301	2,965	0,538 1	0,602 3
35	3,316	2,979	0,546 9	0,610 1
36	3,330	2,991	0,555 4	0,617 5
37	3,343	3,003	0,563 6	0,624 7
38	3,356	3,014	0,571 4	0,631 6
39	3,369	3,025	0,578 9	0,638 2
40	3,381	3,036	0,586 2	0,644 5

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p = number of laboratories at a given level

Note: This table is extended in document [20] to p = 147.

Numerical example

Below, the Grubbs' test is applied to an example of GC analyses of vaporised LNG, in order to determine the presence of outliers, and eliminate them before calculating the average LNG composition. Table A8-2 shows the data from the GC.

Note that if one component is detected as outlier, the whole analysis must be eliminated.

Table A8-2: Example – GC analyses

Analysis	CH_4	C_2H_6	C_3H_8	iC_4	nC_4	iC_5	nC_5	nC_6	N_2	CO_2
1	95,653	3,423	0,728	0,095	0,084	0,002	0,001	0,001	0,014	0,000
2	95,877	3,289	0,603	0,099	0,102	0,005	0,002	0,001	0,024	0,000
3	95,657	3,421	0,726	0,096	0,083	0,002	0,001	0,000	0,014	0,000
4	95,588	3,449	0,751	0,103	0,091	0,003	0,001	0,000	0,014	0,000
5	95,500	3,504	0,769	0,111	0,099	0,003	0,001	0,001	0,013	0,000
6	95,710	3,386	0,714	0,094	0,081	0,002	0,000	0,000	0,013	0,000
7	95,671	3,417	0,719	0,095	0,083	0,002	0,001	0,000	0,014	0,000
8	95,494	3,446	0,774	0,131	0,133	0,006	0,003	0,001	0,013	0,000
9	95,626	3,439	0,734	0,098	0,086	0,002	0,001	0,001	0,013	0,000
10	95,864	3,346	0,596	0,087	0,087	0,004	0,002	0,001	0,013	0,000
11	95,584	3,452	0,747	0,106	0,096	0,003	0,000	0,000	0,012	0,000
12	95,545	3,501	0,752	0,100	0,087	0,003	0,000	0,000	0,013	0,000

Firstly, the Grubb's statistic G_p is calculated for each LNG component and compared to the critical values (see table A8-3). The values of $G_{critical}$ are obtained from table A8-1, for p = 12.

Table A8-3: Example – G_p statistic

	CH_4	C_2H_6	C_3H_8	iC_4	nC_4	iC_5	nC_5	nC_6	N_2	CO_2
x_p	95,877	3,504	0,774	0,131	0,133	0,006	0,003	0,001	0,024	0,000
G_p	1,858	1,343	0,965	2,652	2,805	2,224	2,129	0,957	3,114	0,000
$G_{critical\ 5\%}$	2,412									
$G_{critical\ 1\%}$	2,636									
G_p Ok?	YES	YES	YES	**	**	YES	YES	YES	**	YES

As it is shown in table A8-3, the highest values for the components iC_4, nC_4 and N_2 have been detected as outliers; thus, the two analyses containing these values are excluded (analyses 2 and 8). Next, the test is repeated to the 10 analyses remaining, computing the G_1 statistic. The values of $G_{critical}$ are obtained from table A8-1, for p = 10.

Table A8-4: Example – G_1 statistic

	CH_4	C_2H_6	C_3H_8	iC_4	nC_4	iC_5	nC_5	nC_6	N_2	CO_2
x_1	95,500	3,346	0,596	0,087	0,081	0,002	0,000	0,000	0,012	0,000
G_1	1,389	1,836	2,661	1,686	1,134	0,858	1,265	0,775	1,926	0,000
$G_{critical\ 5\%}$	2,290									
$G_{critical\ 1\%}$	2,482									
G_1 Ok?	YES	YES	**	YES	YES	YES	YES	YES	YES	YES

The lowest value of propane is detected as outlier, and the analysis 10 where it is contained is excluded. Finally, the average composition is calculated with the 9 analyses that have been accepted as correct by the Grubbs' test.

Table A8-5: Example – Average composition

Analysis	**CH_4**	**C_2H_6**	**C_3H_8**	**iC_4**	**nC_4**	**iC_5**	**nC_5**	**nC_6**	**N_2**	**CO_2**
1	95,653	3,423	0,728	0,095	0,084	0,002	0,001	0,001	0,014	0,000
3	95,657	3,421	0,726	0,096	0,083	0,002	0,001	0,000	0,014	0,000
4	95,588	3,449	0,751	0,103	0,091	0,003	0,001	0,000	0,014	0,000
5	95,500	3,504	0,769	0,111	0,099	0,003	0,001	0,001	0,013	0,000
6	95,710	3,386	0,714	0,094	0,081	0,002	0,000	0,000	0,013	0,000
7	95,671	3,417	0,719	0,095	0,083	0,002	0,001	0,000	0,014	0,000
9	95,626	3,439	0,734	0,098	0,086	0,002	0,001	0,001	0,013	0,000
11	95,584	3,452	0,747	0,106	0,096	0,003	0,000	0,000	0,012	0,000
12	95,545	3,501	0,752	0,100	0,087	0,003	0,000	0,000	0,013	0,000
$\bar{x}$	**95,615**	**3,444**	**0,738**	**0,100**	**0,088**	**0,002**	**0,001**	**0,000**	**0,013**	**0,000**

APPENDIX 9: TABLES FOR LNG DENSITY CALCULATION ACCORDING TO NBS (see Section 9)

TABLE A9-1: COMPONENT MOLAR VOLUMES

Component	Molar volume, l/mol						
	118 K	116 K	114 K	112 K	110 K	108 K	106 K
CH_4	0.038817	0.038536	0.038262	0.037995	0.037735	0.037481	0.037234
C_2H_6	0.048356	0.048184	0.048014	0.047845	0.047678	0.047512	0.047348
C_3H_8	0.062939	0.062756	0.062574	0.062392	0.062212	0.062033	0.061855
iC_4H_{10}	0.078844	0.078640	0.078438	0.078236	0.078035	0.077836	0.077637
nC_4H_{10}	0.077344	0.077150	0.076957	0.076765	0.076574	0.076384	0.076194
iC_5H_{12}	0.092251	0.092032	0.091814	0.091596	0.091379	0.091163	0.090948
nC_5H_{12}	0.092095	0.091884	0.091673	0.091462	0.091252	0.091042	0.090833
N_2	0.050885	0.049179	0.047602	0.046231	0.045031	0.043963	0.043002

Source: N.B.S. - Technical note 1030 December 1980.

TABLE A9-2: VOLUME CORRECTION FACTOR, $K1 . 10^3$

Molecular weight of mixture g/mol	Volume reduction, l/mol						
	105 K	110 K	115 K	120 K	125 K	130 K	135 K
16	-0.007	-0.008	-0.009	-0.010	-0.013	-0.015	-0.017
17	0.165	0.180	0.220	0.250	0.295	0.345	0.400
18	0.340	0.375	0.440	0.500	0.590	0.700	0.825
19	0.475	0.535	0.610	0.695	0.795	0.920	1.060
20	0.635	0.725	0.810	0.920	1.035	1.200	1.390
21	0.735	0.835	0.945	1.055	1.210	1.370	1.590
22	0.840	0.950	1.065	1.205	1.385	1.555	1.800
23	0.920	1.055	1.180	1.330	1.525	1.715	1.950
24	1.045	1.155	1.280	1.450	1.640	1.860	2.105
25	1.120	1.245	1.380	1.550	1.750	1.990	2.272

Source: N.B.S. - Technical note 1030 December 1980.

TABLE A9-3: VOLUME CORRECTION FACTOR, K2 . 10^3

Molecular weight of mixture	Volume reduction, l/mol						
	105 K	**110 K**	**115 K**	**120 K**	**125 K**	**130 K**	**135 K**
16	-0.010	-0.015	-0.024	-0.032	-0.043	-0.058	-0.075
17	0.240	0.320	0.410	0.600	0.710	0.950	1.300
18	0.420	0.590	0.720	0.910	1.130	1.460	2.000
19	0.610	0.770	0.950	1.230	1.480	1.920	2.400
20	0.750	0.920	1.150	1.430	1.730	2.200	2.600
21	0.910	1.070	1.220	1.630	1.980	2.420	3.000
22	1.050	1.220	1.300	1.850	2.230	2.680	3.400
23	1.190	1.370	1.450	2.080	2.480	3.000	3.770
24	1.330	1.520	1.650	2.300	2.750	3.320	3.990
25	1.450	1.710	2.000	2.450	2.900	3.520	4.230

Source: N.B.S. - Technical note 1030 December 1980.

APPENDIX 10: EXAMPLE OF LNG DENSITY CALCULATION (see Section 9)

For LNG with composition as indicated in Table A10-1 and A10-2 and at a temperature of 112.38 K

TABLE A10-1

1) CALCULATION OF MOLECULAR WEIGHT IN g/mol (in accordance with ISO 6976:1995)

Molar composition		**Molecular weight**	
Component	**Molar fraction mol/mol**	**Component molecular weight g/mol**	**Molecular weight fract. g/mol**
Methane CH_4	0.89235	16.043	14.315971
Ethane C_2H_6	0.08267	30.070	2.485887
Propane C_3H_8	0.01313	44.097	0.578994
Isobutane Ic_4H_{10}	0.00167	58.123	0.097065
n-Butane nC_4H_{10}	0.00277	58.123	0.161001
Isopentane iC_5H_{12}	0.00011	72.150	0.007937
n-Pentane nC_5H_{12}	0.00000	72.150	0.000000
n-Hexane nC_6H_{14}	0.00000	86.177	0.000000
Nitrogen N_2	0.00730	28.0135	0.204499
TOTAL	1.00000		17.851354

TABLE A10-2

2) CALCULATION OF THE MOLAR VOLUME IN l/mol BY TEMPERATURE INTERPOLATION

At T = 112.38K ⇨Molar volume = $\sum_i$ component molar volumes = $\sum_i$ (mole fractions x molar volumes @ 112.38K)
molar volumes @ 112.38K = linear interpolation between molar volume @ 112 K and 114 K.

$$= \frac{112.38 - 112}{114 - 112}.(0.038262 - 0.037995) + 0.037995 = 0.038046$$

Component	**Mole fraction**	**Molar volume from Table No. 14**		**Differential molar volume for 2 K**	**Differential molar volume for 1.62 K**	**Molar volume at 112.38 K**	**Component molar volume at 112.38 K**
		at 114 K	**at 112 K**				
(1)	(2)	(3)	(4)	(5)=(3)-(4)	(6)=(1.62K/2K).(5)	(7)=(3)-(6)	(8)=(7).(2)
		l/mol	l/mol	l/mol	l/mol	l/mol	l/mol
CH_4	0.892350	0.038262	0.037995	0.000267	0.000216	0.038046	0.033950
C_2H_6	0.082670	0.048014	0.047845	0.000169	0.000137	0.047877	0.003958
C_3H_8	0.013130	0.062574	0.062392	0.000182	0.000147	0.062427	0.000820
iC_4H_{10}	0.001670	0.078438	0.078236	0.000202	0.000164	0.078274	0.000131
nC_4H_{10}	0.002770	0.076957	0.076765	0.000192	0.000156	0.076801	0.000213
iC_5H_{12}	0.000110	0.091814	0.091596	0.000218	0.000171	0.091637	0.000010
N_2	0.007300	0.047602	0.046231	0.001371	0.001111	0.046491	0.000339
TOTAL	1.000000						0.039421

3) CALCULATION OF VOLUME REDUCTION FACTORS k1 AND k2

3.1) Calculation of k1

The k1 values are given for different temperatures and molecular weights in Table A9-2.

Two interpolations must be carried out:
1) on the temperature,
2) on the molecular weight.

TABLE A10-3

T=112.38 K

CALCULATION OF THE CORRECTION FACTOR k1 in l/mol - temperature interpolation

Molecular weight	**k1 at 115 K T1**	**k1 at 110 K T2**	**Differential value for k1 for 5 K**	**Differential value for 2.62 K**	**k1 at 112.38 K**
g/mol	(11)	(12)	(13)=(11)-(12)	(14)=(2.62K/5K).(13)	(15)=(11)-(14)
	l/mol	l/mol	l/mol	l/mol	l/mol
MW_2 (17 g/mol)	0.000220	0.000180	0.000040	0.000021	0.000199
MW_1 (18 g/mol)	0.000440	0.000375	0.000065	0.000034	0.000406

- Molecular weight interpolation factor: $\text{MWI} = \frac{18.0 - 17.851354}{18.0 - 17.0} = 0.148646$

- Volume correction factor k1 at T = 112.38 K and with M.W. = 17.851354 g/mol

$$k1\ (MW,T) = k1\ (MW_1,T) - MW_1\ .\ (k1\ (MW_1,T) - k1\ (MW_2,T))$$

$$= 0.000406 - 0.148646\ .\ (0.000406 - 0.000199)$$

$$k1\ (MW,T) = 0.000375\ \text{l/mol}$$

3.2) Calculation of k2

The k2 values are given for different temperatures and molecular weights in Table A9-3.

TABLE A10-4

CALCULATION OF THE CORRECTION FACTOR k2 in l/mol - temperature interpolation

Molecular weight	**k2 at 115 K**	**k2 at 110 K**	**Differential value for k2 for 5 K**	**Differential value for 2.62 K**	**k2 at 112.38 K**
g/mol	(17)	(18)	(19)=(17)-(18)	(20)=(2.62K/5K).(19)	(21)=(17)-(20)
	l/mol	l/mol	l/mol	l/mol	l/mol
MW_2 (17 g/mol	0.000410	0.000320	0.000090	0.000047	0.000363
MW_1 (18 g/mol)	0.000720	0.000590	0.000130	0.000068	0.000652

- Molecular weight interpolation factor: same as for as k1 MWI= 0.148646.

  - Volume correction factor k2 at T = 112.38 K and with MW = 17.851354 g/mol

$$k2\left(MW,T\right)=k2\left(MW_1,T\right)-MWI\,.\,(k2(MW_1,T)-k2(MW_2,T)) \qquad (24)$$

$$= 0.000652 - 0.148646\ .\ (0.000652 - 0.000363)$$

k2 (MW,T) = 0.000609 l/mol

4) CORRECTED MOLAR VOLUME AND DENSITY

Application of the formula mentioned in Section 9.3.2 yields the following result:

$\Sigma_I X_i V_i$ = 0.039421 g/mol
k1 = 0.000375 l/mol
k2 = 0.000609 l/mol
XN_2 = 0.0073
XCH_4 = 0.89235

V_{mix} = $\Sigma_I X_i V_i$ –round [k1 + (k2 – k1) . round(XN_2/0.0425;6) . XCH_4;6]
= 0.039051 l/mol

M_{mix} = 17.851354 g/mol

D_{LNG} = M_{mix}/V_{mix}
= 457.129241 kg/m^3

which, when rounded off to the nearest thousandth, gives: 457.129 kg/m^3.

APPENDIX 11: EXAMPLE OF GCV CALCULATION (see Section 10.2.2.3)

TABLE A11-1

GROSS CALORIFIC VALUE (kJ/kg)

Component		**Molar fraction**	**Molecular weight component**	**Molecular weight fraction**	**GCV component**	**GCV fraction kJ/mol**
		(1)	(2)	(3)=(1).(2)	(4)	(5)=(4)-(1)
			g/mol	g/mol	kJ/mol	kJ/mol
Methane	CH_4	0.89235	16.043	14.315971	891.56	795.583566
Ethane	C_2H_6	0.08267	30.070	2.485887	1,562.14	129.142114
Propane	C_3H_8	0.01313	44.097	0.578994	2,221.10	29.163043
Isobutane	iC_4H_{10}	0.00167	58.123	0.097065	2,870.58	4.793869
n-Butane	nC_4H_{10}	0.00277	58.123	0.161001	2,879.76	7.976935
Isopentane	iC_5H_{12}	0.00011	72.150	0.007937	3,531.68	0.388485
n-Pentane	nC_5H_{12}	0.00000	72.150	0.000000	3,538.60	0.000000
Nitrogen	N_2	0.00730	28.0135	0.204499	0.00	0.000000
SUM		1.00000		17.851354		967.048012

- The constants used in columns (2) and (4) are taken from ISO 6976:1995.
- The gross calorific value is calculated at 15°C (not at 25°C, cfr. Section 10.1)

GCV = 967.048012/17.851354 MJ/kg
54.172250 MJ/kg
54.172 MJ/kg

or = 54.172250 x 0.947817/1000
0.051345 MMBTU/kg

GROSS CALORIFIC VALUE (kJ/m^3(s)) FOR $E_{GAS\ DISPLACED}$ CALCULATION

In this example the displaced gas molar fractions are estimated by calculation as described in Section 10.2.2.3.

– First step
$N_{2\ gas}$ = 23 $N_{2\ liq}$ = 23 . 0.0073 = 0.1679
$CH_{4\ gas}$ = 1 $CH_{4\ liq}$ = 0.89235
$C_2H_{6\ gas}$ = 0.005 $C_2H_{6\ liq}$ = 0.005 . 0.08267 = 0.000413

Other components in the gaseous state are assumed to equal zero.

– Second step
Linear correction so that the sum equals 1
Correction factor = 1/(0.1679 + 0.89235 + 0.000413)
= 0.942807

This yields the final adjusted values:
$N_{2\ gas}$ = 0.1679 . 0.942807 = 0.158297
$CH_{4\ gas}$ = 0.89235 . 0.942807 = 0.841314
$C_2H_{6\ gas}$ = 0.000413 . 0.942807 = 0.000389

TABLE A11-2

GROSS CALORIFIC VALUE FOR $E_{GAS\ DISPLACED}$ CALCULATION

Components	Molar fraction	GCV component	GCV fraction
	(1)	(2)	(3)=(1).(2)
		MJ/m^3(s)	MJ/m^3(s)
Methane CH_4	0.841314	37.7060	31.722586
Ethane C_2H_6	0.000389	66.0700	0.025701
Propane C_3H_8	0.000000	93.9400	0.000000
Isobutane iC_4H_{10}	0.000000	121.400	0.000000
n-Butane nC_4H_{10}	0.000000	121.790	0.000000
Isopentane iC_5H_{12}	0.000000	149.360	0.000000
n-Pentane nC_5H_{12}	0.000000	149.660	0.000000
Nitrogen N_2	0.158297	0.000	0.000000
	1.00000		31.748287

- The constants used in columns (2) and (4) are taken from ISO 6976.
- The gross calorific value is calculated at standard ISO conditions 15/15°C (calorific reference temperature 15°C, gas volume at 15°C and pressure 1.01325 bar a).

GCV = 31.748287 MJ/m^3(s) (without Z, the compressibility factor)

Z factor is calculated at 15ºC and constants taken from ISO 6976 table 2

Z = 0.998369

GCV return gas = 31.748287/0.998369
GCV (including Z factor) = 31.800153 MJ/m^3(s)

or

GCV = 31.800153 x 0.947817/1000
= 0.030141 MMBTU/m^3(s)

APPENDIX 12: UNCERTAINTY CALCULATIONS (See Section 15)

Gross Calorific Value:

Annex B (normative) of ISO/DIS 6976 establishes the following equation to calculate the uncertainty of the gross calorific value on mass-basis:

$$\left(\frac{u((Hm)_G)}{(Hm)_G}\right)^2 = \sum_{i=1}^{N}\sum_{j=1}^{N}\left(\frac{[(Hc)_G^0]_i}{(Hc)_G} - \frac{M_i}{M}\right)\cdot u(x_i)\cdot r(x_i,x_j)\cdot\left(\frac{[(Hc)_G^0]_j}{(Hc)_G} - \frac{M_j}{M}\right)\cdot u(x_j) + \frac{\sum_{i=1}^{N} x_i^2\cdot u^2([(Hc)_G^0]_i)}{{(Hc)_G}^2} + \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} x_i\cdot u(M_i)\cdot r(M_i,M_j)\cdot x_j\cdot u(M_j)}{M^2}$$

where:

$(Hc)_G$ = gross calorific value on a molar basis (kJ/mol)
$(Hc)_G^0$ = ideal gross calorific value on a molar basis (kJ/mol)
$(Hm)_G$ = gross calorific value on a mass basis (MJ/kg)
M = molar mass (kg/kmol)
u = standard uncertainty
x = mole fraction (-)

Next, there is an example calculation of the GCV uncertainty for the composition of a typical LNG cargo (table A12-1).

TABLE A12-1: COMPOSITION ANALYSIS

component	x_i	$u(x_i)$
methane	0.952	0.001
ethane	0.028	0.00014
propane	0.013	0.000104
nitrogen	0.004	0.00005
propane	0.003	0.00006
sum	1.000	

The resulting GCV on mass basis and expanded uncertainty (k = 2) are 54.788 ± 0.024 MJ/kg:

GCV	54.787 912	MJ/kg
U(GCV)	0.024 (1)	MJ/kg
	0.043 %	

Note (1): ISO/DIS 6976 establishes that the expanded uncertainty shall be rounded to two significant figures, using the normal rules of rounding. The numerical value of the property shall be rounded to the least significant figure in the rounded value of the expanded uncertainty.

For the gross calorific value, the determination of the uncertainty is specified in the ISO standard. However, there are no standards or specifications that establish a detailed uncertainty determination for volume and density. Several examples for the uncertainty of the volume and density can be found in bibliography:

- E. Graham & A. Kenbaar, NEL. *LNG energy transfer uncertainty – Sensitivity to composition and temperature changes*. 16th International Flow Measurement Conference, FLOMEKO 2013, Paris.
- R. Sakariassen, MetroPartner a.s. report *Uncertainty evaluation of LNG energy determination at Melkoya by use of ship tanks*. Doc no. REP-02/1004, Nov 2004.

As a help in the elaboration of the uncertainty determination, typical values of the sources of uncertainty in LNG volume are listed below. Additionally, a brief explanation of the Monte Carlo simulation carried out to determine LNG density uncertainty is given.

Volume:

The following table shows typical values of the sources of uncertainty in LNG volume:

TABLE A12-2: SOURCES OF UNCERTAINTY IN VOLUME

Source of uncertainty	***Typical Value***
Gauge tables	Typically from 0.02 % to 0.3 % (k = 2)
Intrinsic Level gauge	Tolerance from ISO 10976: ± 7.5 mm (k = $\sqrt{3}$)
Liquid temperature	Tolerance from ISO 10976: ± 0.2 ºC[(a)] (k = $\sqrt{3}$)
Vapour temperature	Tolerance from ISO 10976: ± 1 ºC (k = $\sqrt{3}$)
List (if applicable)	Typical calibration tolerance: ± 0.1 m (k = 2)
Trim (if applicable)	Typical calibration tolerance: ± 0.5 º (k = 2)
Tank thermal expansion factor (Spherical tanks)	10 % (k = 2)

[(a)] Sometimes, a more conservative value of ± 0.5 ºC is used.

Density:

The LNG density is calculated according to the revised Klosek-McKinley method:

$$D = \frac{\sum(X_i \times M_i)}{\sum(X_i \times V_i) - X_M \times C} \quad \text{where} \quad C = K_1 + \frac{(K_2 - K_1) \times X_N}{0.0425}$$

The uncertainty in the density is therefore depending on the uncertainty in:

X_i being the mole fraction of each constituent determined by analysis
M_i being the Molecular weight of each of the constituents
V_i being the Molecular volume depending on the temperature of the LNG
X_M being the mole fraction of Methane determined by analysis
X_N being the mole fraction of Nitrogen determined by analysis
K_1 and K_2 being the correction factors for volume reduction of the LNG mixture depending on LNG temperature and the Molecular weight of the mixture as determined by analysis

Due to the complex interaction between the uncertainties of all individual contributors a Monte Carlo simulation is used to calculate the total uncertainty of the LNG density.
Following uncertainty sources are taken into account.

Where $u(x_N)$ is calculated according below formula:

$$\left(\frac{u(x_N)}{x_N} \times \frac{1}{0.0425}\right) \quad [2] \qquad \text{where:} \quad u(x'_N) = \sqrt{u(x_N)^2 + u(x_{N_{cal}})^2} \quad [3]$$

ux_m is calculated according below formula:

$$\frac{u(x_M)}{x_M} \quad [4] \qquad \text{where:} \quad u(x'_M) = \sqrt{u(x_M)^2 + u(x_{M_{cal}})^2} \quad [5]$$

The uncertainties on molecular mass and molecular volume are based on the measurement of individual components by gas chromatograph is calculated following ISO-6976:

$$u(x_iM_i) = \sqrt{\sum_{i=1}^{N}\left[u(x'_i) \times \left(M_i - (x_iM_i)\right)\right]^2} \quad [6]$$

Additional the molecular volume temperature uncertainty is included according below formula:

$$u(x_iV_i) = \sqrt{\sum_{i=1}^{N}\left[u(x'_i) \times \left(V_i - (x_iV_i)\right)\right]^2 + \sum_{i=1}^{N}\left[u(x_i) \times \left(\delta T_{LNG}V_i - (\delta T_{LNG}x_iV_i)\right)\right]^2} \quad [7]$$

Both k_1 and k_2 are depending on molecular weight and LNG temperature and given in tables. The possible error in these values is estimated from maximising the uncertainty in molecular weight and LNG temperature maximum on the interpolations done to get the values for k1 and k2. This error is taken as the standard uncertainty. The combined uncertainty on these correction factors is determined by:

$$u(k) = \sqrt{u(k_1)^2 + u(k_2)^2} \quad [8]$$

For calculating the uncertainty of the LNG density the contributors with their uncertainty references are:

Symbol	Description	Uncertainty	Reference
x_i	Individual component results from gas chromatograph measurement	Amount based acc. ISO tables	ISO 6974-5 online ISO 6974-3 offline
x_N	Nitrogen content in mix	Amount based acc. ISO tables	ISO 6974-5 online ISO 6974-3 offline
x_M	Methane content in mix	Amount based acc. ISO tables	ISO 6974-5 online ISO 6974-3 offline
M_{KM}	Uncertainty of the calculation method acc. revised Klosek-McKinley.	± 0.1%	NBS publication 1080
T_{LNG}	Actual temperature of the LNG	± 0.2°C (T ≤ -145°C)	ISO 10976
x_{cal}	Typical calibration gas composition	Composition (% mol/mol) Nitrogen 0.245 ± 0.011 Methane 93.335 ± 0.02 Ethane 3.729 ± 0.010 Propane 1.493 ± 0.005 i-Butane 0.2990 ± 0.0009 n-Butane 0.5003 ±0.0016 i-Pentane 0.1501 ±0.0009 n-Pentane 0.2480±0.0014	Certificate manufactures (Uncertainties are Expanded Uncertainties (k=2)

A Monte Carlo simulation based on 10.000 iterations taken into account the following individual uncertainties for the individual contributors as described in above:

	Value	standard uncertainty (%)	Coverage Factor	Standard uncertainty (absolute)	Sensitivity	Formula
$\sum(x_i \times M_i)$[kg/kmole]	17.632	0.20	1	0.035	1	[6]
$\sum(x_i \times V_i)$ [m^3/kmole]	0.039	0.130	2	2.535*10^{-5}	1	[7]
x_N [mol/mol]	0.002	0.07	1	4.314*10^{-5}	23.529	[2]
x_M [mol/mol]	0.934	0.101	1	0.001	1	[4]
$k_{1,2}$ [-]	9.973*10^{-5}	9.71	2	4.253*10^{-6}	1	[8]
ρ_{LNG} [kg/m^3]	**478.089**	**0.23**	1	1.080		[1]

Resulting in a standard uncertainty of 0.23% (k=1):
ρ_{LNG} = (478.09 ± 1.08) kg/m3 (k=1)

APPENDIX 13: EXAMPLE OF COMMERCIAL IMPACT OF ROUNDING OF NUMBERS (see Section 15.8)

The commercial impact is shown in this simple example. Typical reported values are:

V= 150 000 m^3
D = 450.30 kg/m^3
GCV = 54.804 MJ/kg

Table A13-1 shows the maximum error (%) and the maximum economic impact taking into account resp. zero, two and three decimal places for volume, density and calorific value. It can be observed that the maximum error is not significant taking into account that the cargo has a value of 35 085 550 $. New economic impact can be observed by multiplying or dividing by 10 if a decimal place is eliminated or added.

Table A13-1: COMMERCIAL IMPACT

Parameter	Units	Value	Real Value Range		Maximum rounding error (%) Note 1	Maximum rounding error ($) Note 2
Volume	m^3	150 000	150 000.5	149 999.5	0.00033	117
Density	kg/m^3	450.30	450.305	450.295	0.00111	390
GCV	MJ/kg	54.804	54.8045	54,8035	0.00091	320
Energy	MJ	3 701 736 180	3 701 823 395	3 701 648 966	0.00236	827

Note 1

Maximum rounding error (%):
V= 150 000 m^3 (= 0.5 % / 150 000 = 0.00033%)
D = 450.30 kg/m^3 (= 0.005% / 450,30 = 0.011%)
GCV = 54.804 MJ/kg (= 0.0005% / 54.804 = 0.00091%)
E: 0.00236% (=(3 701 823 395 – 3 701 648 966)/3 701 736 180*100)

Note 2

1 Megajoule [MJ] = 0.000947813 Million British Thermal Units [MMBtu]
Energy Cargo (example): 3 701 736 180 MJ/m^3 or 3 508 555 MMBtu
Price LNG (USD/MMBTU) 10.00
Maximum rounding error ($):
rounding volume: 3 508 555*10*0.00033% = 117 $
rounding density: 3 508 555*10*0.00111% = 390 $
rounding GCV: 3 508 555*10*0.00091% = 320 $
rounding energy: 3 508 555*10*0.00236% = 827 $

APPENDIX 14: TWO CASE STUDIES ILLUSTRATING POTENTIAL RISKS OF STRATIFICATION AND ROLLOVER IN LNG SHIP'S CARGO TANKS

For information only, see Reference [12]

Case study No. 1: Density-stratified liquid layers in LNG cargo tanks upon arrival at importing terminal

The table below shows a comparison of the LNG temperatures over the height of 5 cargo tanks recorded at the closing CTS at the export terminal with those recorded at the opening CTS at the import terminal, and the temperature difference between both.

CT = Cargo tank No.
DEP = Closing Custody Transfer Survey upon DEParture at the export terminal
ARR = Opening Custody Transfer Survey upon ARRival at the import terminal
∆ T = temperature difference

Temperatures °C		CT #1	CT #2	CT #3	CT #4	CT #5
T vapour	DEP	-150.00	-132.00	-140.00	-137.00	-140.00
	ARR	-152.00	-155.00	-150.00	-151.00	-155.00
	∆ T	-2.00	-23.00	-10.00	-14.00	-15.00
T1	DEP	-160.72	-160.72	-160.73	-160.86	-160.73
	ARR	-160.65	-160.66	-160.72	-160.75	-160.68
	∆ T	+0.07	+0.06	+0.01	+0.09	+0.05
T2	DEP	-160.65	-160.66	-160.72	-160.75	-160.68
	ARR	-160.41	-160.55	-160.55	-160.53	-160.53
	∆ T	+0.24	+0.11	+0.17	+0.22	+0.15
T3	DEP	-160.63	-160.27	-160.43	-160.51	-160.39
	ARR	-160.39	-160.46	-159.91	-159.82	-160.52
	∆ T	+0.24	-0.19	+0.52	+0.69	-0.13
T4	DEP	-160.25	-160.40	-160.49	-160.48	-160.48
	ARR	-157.61	-158.36	-158.52	-158.53	-158.46
	∆ T	**+2.64**	**+2.04**	**+1.97**	**+1.95**	**+2.02**
T5	DEP	-160.30	-160.49	-160.48	-160.50	-160.47
	ARR	-157.61	-158.41	-158.51	-158.51	-158.45
	∆ T	**+2.69**	**+2.08**	**+1.97**	**+1.99**	**+2.02**

From this table, and especially the figures in **bold**, it can be seen that between the closing custody transfer survey upon loading and the opening custody transfer survey before unloading, substantial shifts in liquid temperature occurred onboard the LNG carrier, indicating stratification in these cargo tanks.

Sequence of events

- During loading pumping was switched from an LNG shore tank with lower density to one with much higher density (Density difference: 20 kg/m³).
- Since the cargo tanks have bottom fill only, a stable denser bottom layer was induced during loading.
- This layer warmed up during the loaded voyage.
- Because of the substantial density difference, warming up by up to 2.69°C did not induce a sufficient density decrease to destabilize the bottom layer: even after this substantial temperature increase, its density was still higher than that of the upper layer.
- As this bottom layer was the first one to be pumped out on unloading, immediate extensive flashing in the shore tanks occurred, causing a sharp pressure increase resulting in the opening of a shore tank safety relief valve.
- The number of running cargo tank pumps had to be reduced from 6 at the time of the relief valve opening to 4. Even then the large unloading compressor (30 ton/h BOG) had to be started, instead of the usual two BOG compressors at 4 ton/h each.
- As soon as the discontinuous LNG analysis indicated that the lighter layer started to come through, the shore tank pressure decreased and the large unloading compressor could be stopped, and the number of running cargo pumps could be increased to the normal 10.
- Analysis of the LNG composition combined with the unloading flow indicated that the cargo had consisted of about 30% high density LNG, 20% intermediate mixture and 50% lighter density.
- About 58 tons of flash gas had to be flared.

Lessons learned

- If the crew of a loaded LNG carrier detects density stratified layers on board on its way to a receiving LNG terminal, the master should notify the receiving terminal and propose a special pre-discharge meeting on board focusing on this issue. At this meeting ship and shore should agree how to take appropriate precautions in concert.
- How to detect stratified layers on board an LNG carrier that did not notify the receiving terminal in advance? Make sure that for the opening CTS you always have the Bill of Lading at hand to compare the temperature profile in each cargo tank and the tank pressure with those upon departure at the loading terminal. If you detect any abnormality such as shown in the above table, then immediately notify the master or cargo officer of this and develop an appropriate unloading strategy in concert with the ship. For instance, start unloading at an intentionally reduced rate, e.g. with 4 pumps only. Check that the vapour return rate from the ship is not excessive. If not, then you can gradually increase the unloading rate by running more LNG transfer pumps on board ship.
- Calculate the SVP (= saturated vapour pressure, calculated based on the LNG composition at loading and current LNG liquid temperatures upon arrival at the unloading terminal), and compare this SVP with the actual tank pressure in the ship's cargo tanks.
- If the SVP is substantially higher (e.g. more than 20 mbar or 2 kPa) than the actual tank pressure in the ship's cargo tanks, then expect excessive flash gas upon unloading and act very prudently especially at the beginning of the unloading operation. As a guidance, a rule of thumb is that for every 0.1°C temperature increase of a given LNG batch, the saturated vapour pressure increases by approx. 10 mbar ±3 mbar (i.e. 7 … 13 mbar).
- Stratification and rollover in one or more ship's cargo tanks are detrimental for a proper and accurate custody transfer upon unloading.
- When loading LNG cargo tanks check that the LNG batch designated to be loaded is as homogeneous as possible. As a guide it is proposed that LNG density differences be less than 1 kg/m³, temperature differences less than 0.5°C, differences in saturated vapour pressure less than 10 mbar and the LNG composition as similar as possible.

Case study No. 2: density-stratified liquid layers in LNG cargo tanks upon departure at exporting terminal

The table below shows a comparison of the LNG temperatures over the height of 5 cargo tanks recorded at the closing CTS at the export terminal with those recorded at the opening CTS at the import terminal, and the temperature difference between both.

CT = Cargo tank No.
DEP = Closing Custody Transfer Survey before DEParture at the export terminal
ARR = Opening Custody Transfer Survey upon ARRival at the import terminal
∆ T = temperature difference

Temperatures °C		**CT #1**	**CT #2**	**CT #3**	**CT #4**	**CT #5**
T1 TOP (vapour dome)	DEP	-150.25	-149.01	-139.16	-121.07	-146.44
	ARR	-143.30	-143.47	-144.94	-154.25	-144.12
	∆ T	+6.95	+5.54	**-5.78**	**-33.18**	+2.32
T2 85% level	DEP	-159.14	-158.82	-160.00	-160.37	-158.95
	ARR	-158.78	-158.40	-158.49	-158.48	-158.64
	∆ T	+0.36	+0.42	**+1.51**	**+1.89**	+0.31
T3 50% level	DEP	-158.82	-158.93	-157.65	-157.62	-158.85
	ARR	-158.27	-158.38	-158.37	-157.97	-158.29
	∆ T	+0.55	+0.55	**-0.72**	**-0.35**	+0.56
T4 Bottom	DEP	-159.20	-158.95	-158.16	-158.38	-158.97
	ARR	-158.80	-158.59	-158.67	-158.68	-158.91
	∆ T	+0.40	+0.36	**-0.51**	**-0.30**	+0.06

From this table (see figures in **bold**) it can be seen that between the closing custody transfer survey upon loading and the opening custody transfer survey before unloading, substantial shifts in both vapour and liquid temperature occurred in cargo tanks #3 and #4, indicating stratification in these cargo tanks.

Sequence of events

- Previous LNG cargo: LNG cargo with lighter density.
- Approx. 8 500 m³ LNG was retained onboard as heel in CT#3 and CT#4 in view of a 7-week voyage to the loading terminal
- After 2-weeks voyage, vessel was assigned to load at a receiving LNG terminal instead. Upon arrival there was still approximately 5 400 m³ heel onboard.
- Loading operation at receiving terminal: loading rate was max. 4 200 m³/h instead of the usual 11 000 m³/h at export terminals (bottleneck: terminal loading pump capacity)
- Equator temperature in ship's spherical cargo tanks must be < -134°C when the liquid level reaches 1 metre below the equator level. The vessel would normally conduct spraying operations during loading in order to meet this requirement.
- The terminal vapour system could not accept mist (droplets) in the vapour returned from the vessel. Therefore the vessel was not able to conduct spraying operations during the loading.
- The vessel stopped loading each tank for 2-7 hours at 1 metre below the equator level to ensure that the equator was cooled to below –134°C.
- The above factors may have contributed to the formation of density-stratified liquid layers in the heel tanks.
- On completion of loading there was a big differential between temperature sensor T2 (located at 85% of tank height) and T3 & T4 (located at 50% of tank height = equator, and cargo tank bottom respectively).
- Loaded voyage to unloading port: 5-7 Beaufort, swell 1-2 metres, very little rolling or vibration, low voyage speed approximately 12 knots.
- Increase in liquid levels noted in cargo tanks #3 and #4.
- Liquid level in CT #3 increased until one day after loaded departure.
- Liquid level in CT #4 increased until three days after loaded departure.
- Once rollover occurred the liquid level went down rapidly.
- Liquid level became steady when the circumstances (temperature, pressure) in the tank had stabilised.
- Vapour temperature cooled after the liquid level came down in CT #3, which indicates the generation of significant more BOG.
- 5 days after loaded departure, rollover occurred in cargo tank #3: upper and lower liquid temperature rapidly changed (within some 5 hours): upper liquid temperature T2 increased, lower liquid temperatures T3 & T4 decreased, temperature in vapour dome dropped by 6°C in some 5 hours.
- 6 days after loaded departure and 1 day after rollover in cargo tank # 3, the crew started spray pump in cargo tank #4 to encourage intentional rollover under controlled conditions: spraying was stopped when tank pressure reached 18 kPa (180 mbarg).
- 7 days after loaded departure rollover occurred in cargo tank #4 about 1 hour after encouraging it:
    - again the upper liquid temperature T2 rose rapidly while the lower liquid temperatures T3 & T4 dropped rapidly by more than 1°C within approximately one hour, i.e. much faster than during the spontaneous rollover in cargo tank #3
    - during this rollover in cargo tank #4, the vapour temperature in the tank dome (T1) dropped by more than 11°C
- Cargo tank pressure in cargo tank #3: during rollover in CT #3 tank pressure rose from 11.5 kPa to 16.5 kPa, whereas during rollover in CT #4 the next day tank pressure in CT #3 even rose from 11.5 kPa to 20 kPa.
- When the crew detected that rollover had occurred in cargo tanks #3 and #4, all vapour suction valves except those of cargo tanks #3 and #4 were closed down to the minimum open position necessary and sufficient to maintain safe tank pressures in cargo tanks #1, #2 and #5, in order to remove as much BOG as possible from the rollover cargo tanks #3 and #4.
- On berthing at the unloading terminal, the liquid temperatures and the tank pressures were not yet at a safe level to conduct the opening CTS and the ESD trip tests. So the master of the vessel coordinated with the terminal to send excess BOG from ship to shore flare, to reach a stable condition as soon as possible.

Lessons learned

These two rollover events in CT #3 and CT #4 were rather mild rollovers: the cargotank pressures were maintained within design parameters at all times. However the incident demonstrated that:

- Although it was previously believed by many that rollover would be unlikely to occur in a Moss-Rosenberg type cargo tank, because the spherical shape of the tank would aid the migration of the warmed liquid along the tank wall, clearly, it did not do so sufficiently in this case.
- Stratification and rollover conditions can develop on board ship particularly when (bottom) (re)loading a higher density LNG into a tank containing a heel or cargo with lighter density.
- Ship movement on passage cannot be relied upon to mix layers of different density.

- An increase of the liquid level in one or more cargo tanks may be an indication of stratification. The shape of spherical cargo tanks act as a “magnifying lens” for readily noting changes in volume.
- Reduction in boil-off gas generation may indicate stratification.
- Stratification and rollover in one or more ship’s cargo tanks are detrimental for a proper and accurate custody transfer upon unloading.

Recommendations for a proper custody transfer when partial reloading

- Avoid filling a cargo tank with a heel of more than 1 m heel height

- If due to practical circumstances a heel of more than 1 m cannot be avoided, then the following is recommended. Check that the physical properties of the LNG cargo to be reloaded are as close as possible to those of the heel in the cargo tank, e.g. LNG density difference less than 1 kg/m³ and preferably lower than the density of the heel, temperature difference not more than 0.5°C, difference in saturated vapour pressure not more than 30 mbar.

APPENDIX 15: EXAMPLE OF CUSTODY TRANSFER DATA LOGS ON BOARD A LNG VESSEL

For information only – see Reference [13]

Example of custody transfer data before unloading

SHIP NAME
DATE
LOCAL TIME
PORT NAME
CARGO NO
CHIEF OFFICER

TRIM (METER)	0,05	BY STERN
LIST (DEGREE)	0,1	TO STARBOARD

LEVEL (m)	TANK 1	TANK2	TANK 3	TANK 4
№.1	37,332	37,05	37,488	37,388
№.2	37,333	37,051	37,488	37,39
№.3	37,332	37,051	37,487	37,391
№.4	37,332	37,051	37,487	37,392
№.5	37,332	37,051	37,486	37,392
AVERAGE LEVEL (m)	37,332	37,051	37,487	37,391

TRIM CORRECTION (m)	0	0	0	0
LIST CORRECTION (m)	-0,001	-0,001	-0,001	-0,001
THERMAL CORRECTION (m)	-0,14	-0,141	-0,141	-0,141
CORRECTED LEVEL (m)	37,191	36,909	37,345	37,249
TANK VOLUME (m^3)	35 840,527	35 701,728	35 912,842	35 868,054
VOLUME SUMMED	143 323,151	m^3 @ –160 DEG C		
THERMAL EXPANSION FACTOR	1,00002	@ –159,2 DEC C		
CORRECTED LIQUID VOLUME	143 326,017	m^3 @ –159,2 DEG C		

TEMPERATURE (°C)				
100 %	-131,96 V	–137,24 V	–134,68 V	–137,58 V
75 %	-159,3 L	–159,24 L	–159,33 L	–158,62 L
50 %	-159,31 L	–159,25 L	–159,36 L	–158,61 L
25 %	-159,34 L	–159,23 L	–159,40 L	–158,79 L
0 %	-159,31 L	–159,24 L	–159,36 L	–158,94 L

TANK AVG VAPOUR TEMP (°C)	–132,0	–137,2	–134,7	–137,6
SHIP'S AVG VAPOUR TEMP (°C)	–135,4			
TANK AVG LIQUID TEMP (°C)	–159,3	–159,2	–159,4	–158,7
SHIP'S AVG LIQUID TEMP (°C)	–159,2			
TANK VAPOUR PRESSURE (kPa(a))	112,2	111,9	112,2	112,2
SHIP'S AVG VAPOUR PRESSURE (kPa(a))	112,1			

	COMPANY	NAME
SHIP'S MASTER		
BUYER(S)		
SELLER(S)		
SURVEYOR		

Example of custody transfer data after unloading

SHIP NAME
DATE
LOCAL TIME
PORT NAME
CARGO NO
CHIEF OFFICER

TRIM (METER)	0	BY STERN
LIST (DEGREE)	0,03	TO STARBOARD

LEVEL (m)	TANK 1	TANK 2	TANK 3	TANK 4
№.1	0,695	5,885	0,612	0,567
№.2	0,696	5,885	0,612	0,567
№.3	0,695	5,885	0,612	0,567
№.4	0,694	5,885	0,612	0,567
№.5	0,695	5,885	0,611	0,566
AVERAGE LEVEL (m)	0,695	5,885	0,612	0,567

TRIM CORRECTION (m)	0	0	0	0
LIST CORRECTION (m)	0	0	0	0
THERMAL CORRECTION (m)	–0,122	–0,128	–0,123	–0,123
CORRECTED LEVEL (m)	0,573	5,757	0,489	0,444
TANK VOLUME (m^3)	20,858	1 952,047	14,474	11,785

VOLUME SUMMED	1 999,164	m^3 @ –160 DEG C
THERMAL EXPANSION FACTOR	1,00002	@ –159,2 DEC C
CORRECTED LIQUID VOLUME	1 999,204	m^3 @ –159,2 DEG C

TEMPERATURE (°C)								
100 %	–61,44	V	–68,34	V	–64,00	V	–64,40	V
75 %	–103,82	V	–114,44	V	–104,33	V	–106,44	V
50 %	–151,60	V	–153,28	V	–151,38	V	–151,58	V
25 %	–157,69	V	–158,42	V	–157,88	V	–157,80	V
0 %	–159,12	L	–159,39	L	–159,01	L	–158,90	L

TANK AVG VAPOUR TEMP (°C)	–118,6	–123,6	–119,4	–120,1
SHIP'S AVG VAPOUR TEMP (°C)	–120,4			

TANK AVG LIQUID TEMP (°C)	–159,1	–159,4	–159,0	–158,9
SHIP'S AVG LIQUID TEMP (°C)	–159,1			

TANK VAPOUR PRESSURE (kPa(a))	111,1	110,7	111,1	111,1
SHIP'S AVG VAPOUR PRESSURE (kPa(a))	111			

	COMPANY	NAME
SHIP'S MASTER		
BUYER(S)		
SELLER(S)		
SURVEYOR		

Example of certificate of unloading

AFTER UNLOADING

DATE		
LOCAL TIME		
TRIM (METER)	0	BY STERN
LIST (DEGREE)	0,03	TO STARBOARD

	TANK 1	TANK 2	TANK 3	TANK 4
AVERAGE LEVEL (m)	0,695	5,885	0,612	0,567
TRIM CORRECTION (m)	0	0	0	0
LIST CORRECTION (m)	0	0	0	0
THERMAL CORRECTION (m)	–0,122	–0,128	–0,123	–0,123
CORRECTED LEVEL (m)	0,573	5,757	0,489	0,444
TANK AVG VAPOUR TEMP (°C)	–118,6	–123,6	–119,4	–120,1
SHIP'S AVG VAPOUR TEMP (°C)	–120,4			
TANK AVG LIQUID TEMP (°C)	–159,1	–159,4	–159,0	–158,9
SHIP'S AVG LIQUID TEMP (°C)	–159,1			
TANK VAPOUR PRESS. (kPa(a))	111,1	110,7	111,1	111,1
SHIP'S AVG VAPOUR PRESS. (kPa(a))	111			
TANK VOLUME (m^3)	20,858	1 952,047	14,474	11,785
VOLUME SUMMED	1 999,164	m^3 @ –160 °C		
THERMAL EXPANSION FACTOR	1,00002	@ –159,2 °C		
CORRECTED LIQUID VOLUME	1 999,204	m^3@ –159,2 °C (B)		

VOLUME UNLOADED (m^3)	141 326,813	(A – B)	141 327	(A – B)

	COMPANY	NAME
SHIP'S MASTER		
BUYER(S)		
SELLER(S)		
SURVEYOR		